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Formalizing Citizen Science: Creating A New Paradigm In Space Weather Policy

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FORMALIZING CITIZEN SCIENCE: CREATING A NEW PARADIGM IN SPACE WEATHER POLICY

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TABLE OF CONTENTS

LIST OF FIGURES……....v

LIST OF TABLES……..vi

ACKNOWLEDGEMENTS…….…..vii

GLOSSARY…….viii

ABBREVIATIONS AND ACROYNMS……...ix

ABSTRACT…….…….....x

CHAPTER

I. INTRODUCTION…….……...….1

II. METHODOLOGY……8

III. ASSESSING POLICY & LAW BETWEEN SPACE WEATHER AND CITIZEN SCIENCE…….....10

Space Weather Review…….…….....10

Space Weather Summary.....…….…….....27

Citizen Science Review…….……29

Citizen Science Summary……..…..…..48

IV. HOW THE POLICY SHOULD CHANGE……...……...……...50

Memorandum to the Heads of Executive Departments and Agencies……..51

Overview….....…….…….....51

Principles for Effective Use of Citizen Science in Space Weather……....53

Responsibilities for the Agency Coordinator for Citizen Science……..54

Future Areas in Space Weather That Could Benefit From Citizen Science…...56

Challenges of Citizen Science in Space Weather……...57

Summary…….59

V. IMPLEMENTING THE CHANGE……60

Plans……..…….…….....60

Procedures…….....…….……...62

Success Metrics……..64

VI. BROADER IMPACTS……66

Space Weather Certification.…….....66

VII. CONCLUSIONS…….74

REFERENCES……..78

LIST OF FIGURES

Figures Page

1. SCISTARTER PROJECTS…….....2

2. METHODOLOGY FLOWCHART……...7

3. AURORASAURUS PROJECT……...33

4. SOLAR WIND POWER……..35

5. HAMSCI PROJECT……41

6. REVERSE BEACON NETWORK…….44

LIST OF TABLES

Tables Page

1. CITIZEN SCIENCE PROJECTS……....32

2. NASA ROSES 2019……59

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GLOSSARY

Bill – A Bill is a proposed legislation that has not yet passed the federal legislation process. Once it is passed by both houses of Congress, and then signed by the President, it becomes law.

Citizen Science – Citizen Science is a field that has continued to evolve, especially as modern technology continues to advance. Citizen Science is when the public voluntarily helps collect and analyze data to address or contribute to a greater goal or need. It is common to see the public interact with and work alongside scientist during their participation in a Citizen Science project. These projects include many STEM disciplines and participants from all over the world.

Executive Order – An Executive Order is a directive that comes from the President of the United States. This manages the operations of the federal government and agencies. Unlike a Policy, an Executive Order does have the force of law.

Policy – Policy is a set of guidelines that are recommended for the federal government or agencies to follow. They are issued with the expectation that participating agencies will act in good faith and follow them, although they do not have the force of law.

Space Weather – Space weather can be described as the Sun – Earth interaction of different kinds of Space Weather phenomena. Space Weather has been recognized as a global challenge amongst Nations as it poses a threat to the US infrastructure, national security and daily luxuries. Solar flares, solar storms, solar radiation storms and coronal holes are the four main types of Space Weather that impact our modern world. The thesis herein will go into greater detail about these events and what kind of impacts they cause.

ABBREVIATIONS AND ACROYNMS

ACE	Advanced Composition Explorer
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOS	Department of State
DOT	Department of Transportation
DSCOVR	Deep Space Climate Observatory
EMP	Electromagnetic Pulse
FEMA	Federal Emergency Management Agency
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric
NSF	National Science Foundation
NWS	National Weather Service
SOHO	Solar and Heliospheric Observatory
STEM	Science, Technology, Engineering and Mathematics
SWORM	Space Weather Operations, Research and Mitigation
SWPC	Space Weather Prediction Center
USSR	Union of Soviet Socialist Republics

ABSTRACT

Space Weather and Citizen Science are two fields that continue to evolve with our ever-growing technology. With that, comes new and evolving Policy, in both fields. “In citizen science, the public participates voluntarily in the scientific process, addressing real-world problems in ways that may include formulating research questions, conducting scientific experiments, collecting and analyzing data, interpreting results, making new discoveries, developing technologies and applications, and solving complex problems.”[1] “Space Weather refers to the environmental conditions in Earth's magnetosphere, ionosphere and thermosphere due to the Sun and the solar wind that can influence the functioning and reliability of spaceborne and ground-based systems and services or endanger property or human health.”[2] Space Weather has gained national and international attention, appearing in our National Space Policy, and has become the focal point of Presidential Executive orders in recent years. Citizen Science has also grown over recent years with the improved abilities of smart phones and technology that is being made available to the vast majority of people across the country and even the world. A Policy document about using Citizen Science to address challenges was also released during the Obama administration. A review of the Space Weather Policy in the United States shows that Policy is supporting and asking got valuable public engagement and education, as well as research and international cooperation from other agencies. Herein, it will be argued that particular Citizen Science activities could be implemented to address the specific goals and objectives in the US Space Weather Policy.

[1] CitizenScience.gov. “About CitizenScience.gov.” https://www.citizenscience.gov/#
[2] European Space Agency. “What is Space Weather.” http://swe.ssa.esa.int/what-is-space-weather

CHAPTER I

INTRODUCTION

Citizen Science[3] over the last few years has been a growing field of interest, one that engages the public and advances our technology. Through Citizen Science and crowdsourcing projects, we are seeing societal needs addressed[4] and science research accelerated.[5,6] Other benefits include providing hands-on learning in science, technology, engineering and mathematics (STEM), and connecting members of the public directly to Federal agency missions and to each other. The hands on learning is coming in many unique ways, whether it is through a mobile app, social media, in person and other online platforms. In a technology dependent world, Citizen Science exploits previously underutilized resources to conduct scientific experiments and solves complex problems. Citizen Science also helps to recruit and engage younger generations to pursue a career in STEM.

The term "Citizen Science" has only been recently coined[7], but its participants have existed for centuries[8]. In fact, April 14th, 2019 marked the fourth annual Citizen Science day. Figure 1 shows the number of Citizen Science projects and events added to the SciStarter database by year. There is a noticeable jump in projects in 2016 and onward, which lines up with

[3] A citizen scientist is an individual who voluntarily contributes his or her time, effort and resources toward scientific research in collaboration with professional scientists or alone. "Amatuer science," "crowdsourced science," "volunteer monitoring," and "public participation in scientific research" are also common aliases for citizen science. https://scistarter.com/citizenscience.html

[4] Sarah Bates, "Tapping Communities for Water Research" last modified March 22, 2018. https://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=244861

[5] Elizabeth MacDonald et al. "New Science in Plain Sight," *Science advances* 4, no. 3 (2018): 1 – 5, doi:10.1126/sciadv.aaq0030

[6] Nathan Case et al. "Using citizen science reports to define the equatorial extent of auroral visibility," *Space Weather*, 14 (2016): 198 – 209, doi:10.1002/2015SW001320.

[7] For a discussion on the etymology of the term, see https://en.wikipedia.org/wiki/Citizen_science

[8] Ben Franklin is one famous citizen scientist in history. https://cosmoquest.org/x/about-cosmoquest/history-of-citizen-science/

the first annual Citizen Science day back in 2016. Projects range across many STEM disciplines, including computer science, ecology, statistics, engineering, medicine, space science, astronomy, and plenty more. Citizen Science projects have been contributing to astronomy and space science for several years now.[9] No formal science background is needed either; the public can contribute meaningful data to these projects all while learning more about the field. Several examples are the Community Collaborative Rain, Hail & Snow Network (CoCoRaHS) project, Aurorasaurus and Ham Radio Science Citizen Investigation (HamSCI).

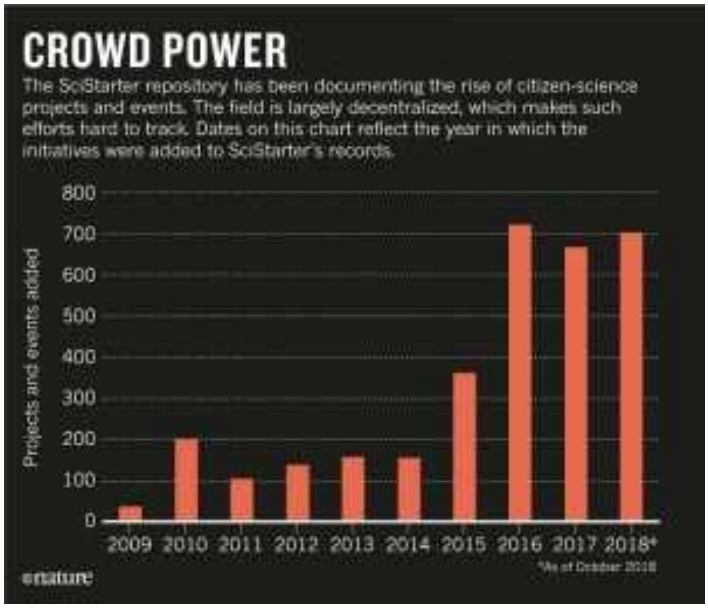

Figure 1. Number of SciStarter Citizen Science projects and efforts that have been added been year (Credit: SciStarter).

Citizen Science has seen supporting Policy around it as the field has continued to grow and come to the attention of more people, especially Policy makers.[10] In terms of White House Office of Science and technology Policy (OSTP), Citizen Science is included but it is absent in

[9] Carol Christian et al. "Citizen Science: Contributions to Astronomy Research," *Organizations, People and Strategies in Astronomy Vol. 1*, (2012): 183 – 197.
[10] John Holdren. "Addressing Societal and Scientific Challenges through Citizen Science and Crowdsourcing." *Memorandum to the Heads of Executive Departments and Agencies, Executive Office of the President, Office of Science and Technology Policy. Sept 30th. Accessed* 23 (2017): 1 – 11. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/holdren_citizen_science_memo_092915_0.pdf

Space Weather Policy. The thesis herein argues that within a field like space weather, where Citizen Science can contribute to engaging the public, educating them and enhancing the scientific research, it should be a field that is encouraged within Space Weather Policy. For instance, in our current National Space Policy[11], the term Citizen Science, crowdsourcing and other such like aliases do not appear once in the document. After this thesis investigated current Space Weather Policy principles, goals and guidelines, it was evident that Citizen Science could contribute to what the Policy sought after.

Every President sets their own national space Policy. The thesis herein will examine the current National Space Policy that was released from the Obama administration as well as the Space Policy Directives from the Trump administration. On December 11th, 2017 President Trump signed Space Policy Directive-1[12], the first of such directives. Essentially it replaced sending humans to an asteroid by 2025 and restoring the Moon as the primary focus of human spaceflight. Nevertheless, there is mention of several areas within the National Space Policy where Citizen Science could help:

1. **Engaging and educating the public**: "Space operations should be conducted in ways that emphasize openness and transparency to improve public awareness of the activities of Government, and enable others to share in the benefits provided by the use of space."[13]
2. **Improve research capabilities to conduct science**: "Continue a strong program of space science for observations, research, and analysis of our Sun, solar system, and universe to enhance knowledge of the cosmos, further our understanding of fundamental natural and

[11] Barack Obama. United States. Office of the Press Secretary. "National Space Policy of the United States of America." 2010. Washington, D.C. 1 – 14.
https://obamawhitehouse.archives.gov/sites/default/files/national_space_policy_6-28-10.pdf
[12] Donald Trump. "Presidential Memorandum on Reinvigorating America's Human Space Exploration Program". Last modified December 11, 2017.
[13] Obama, *National Space Policy*, 3.

physical sciences, understand the conditions that may support the development of life, and search for planetary bodies and Earth-like planets in orbit around other stars."[14]

3. **Further International Cooperation**: "Expand international cooperation on mutually beneficial space activities to: broaden and extend the benefits of space; further the peaceful use of space; and enhance collection and partnership in sharing of space-derived information."[15]

Other Space Weather Policy documents also share these common three themes that are highlighted above. These three themes include actions that are already being accomplished by Citizen Science projects across the country. While the field of Citizen Science may being doing just fine on its own, this thesis herein will argue it needs to be utilized even more and promoted in future Space Weather Policy. Formalizing it in the Policy will assure agencies are given proper principles on using Citizen Science appropriately and to make the maximum possible impact in their respective fields. Using Citizen Science will only help get the most out of what current Space Weather Policy is asking for. It will take an already existing and successful science and apply it to the needs of what our current Space Weather Policy is asking for. There are further benefits from Citizen Science than the three highlighted above, for example: "after analyzing 338 Citizen Science biodiversity projects around the world, researchers at the University of Washington estimated that the in-kind contributions of 1.3–2.3 million Citizen

[14] Ibid, 11.
[15] Ibid, 4.

Science volunteers to biodiversity research have an economic value of up to $2.5 billion per year."[16]

First, what is space weather and why would the US Government be concerned about it? Space weather refers to the Sun-Earth interaction, as our Sun is the main source of space weather. Space weather phenomena and their impacts pose a threat to the US infrastructure, daily luxuries and national security. Here are the main four space weather phenomena that impact our modern world:

Solar Flares: These are large eruptions of electromagnetic radiation that sometimes last for minutes or even hours. Since they travel at the speed of light, Earth is able to feel their impacts immediately but only on the Sunlit side of Earth. Solar flares can disrupt HF Radio Communications which is used by ham radio operators, commercial airlines, FEMA and the DoD. Extreme solar flares occur, on average, less than 1 time every 11 years but minor solar flares occur, on average, 2,000 times every 11 years.

Solar Storms (CMEs): Solar storms, also known as Coronal Mass Ejections (CMEs), are large eruptions of plasma. They are often associated with solar flares and typically take about two to four days to arrive at Earth. Solar storms pose a threat to GPS Systems, the Electric Power Grid, HF Radio Communications and Satellite Communications. Extreme solar storms occur, on average, 4 times every 11 years but minor solar storms occur, on average, 1,700 times every 11 years.

Solar Radiation Storms (SEPs): Solar radiation storms are a result from solar flares and solar storms that consist of charged particles. These energetic particles are accelerated at

[16] E.J. Theobald et al. "Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research," *Biological Conservation Vol. 181*, (2015): 236 – 244. https://doi.org/10.1016/j.biocon.2014.10.021

1/3 the speed of light which allows them to reach Earth in just 30 minutes. The protons are the biggest concern as they pose a threat to satellites and humans in space. They are able to damage electronic circuits onboard the satellite and cause harmful radiation to astronauts if proper precaution is not taken. Solar radiation storms are also a threat to airline crew and passengers that are flying at high latitudes due to elevated radiation doses. Extreme solar radiation storms occur, on average, less than 1 time every 11 years but minor solar radiation storms occur, on average, 50 times every 11 years.

Coronal Holes: Coronal holes appear as darker regions in the Sun's corona. These areas of open magnetic field lines allow faster solar wind to escape. They can be persistent and last several solar rotations (27-day periods). When they arrive at Earth, they can cause similar impacts as solar storms but usually to a lesser degree. Coronal holes can impact HF Radio communications and GPS Systems due to the associated and elevated geomagnetic activity they can potentially bring.

The thesis herein will demonstrate how future Space Weather Policy should change, how to implement this change and then discuss a broader impact that was found during this research. It will also demonstrate what motivated this research to be conducted. After having about two years of work experience with the Aurorasaurus Citizen Science project and choosing the Policy route within the Space Studies program, it was clear to the thesis author that these two fields could benefit from each other. This research will recognize what is being accomplished in the Citizen Science field, describe the current state of Space Weather Policy and elaborate on where and why they need to coexist together. The goal is to have this paper be a first of its kind, by taking two, well researched fields and combining them to have a Citizen Science Space Weather Policy document for future decision makers to reference in their process of drafting new Policy.

The following chapter will be a comprehensive review of this thesis' structure. It highlights the approach and steps taken, to arrive at the conclusion of how Space Weather Policy and Citizen Science should coexist.

CHAPTER II

METHODOLOGY

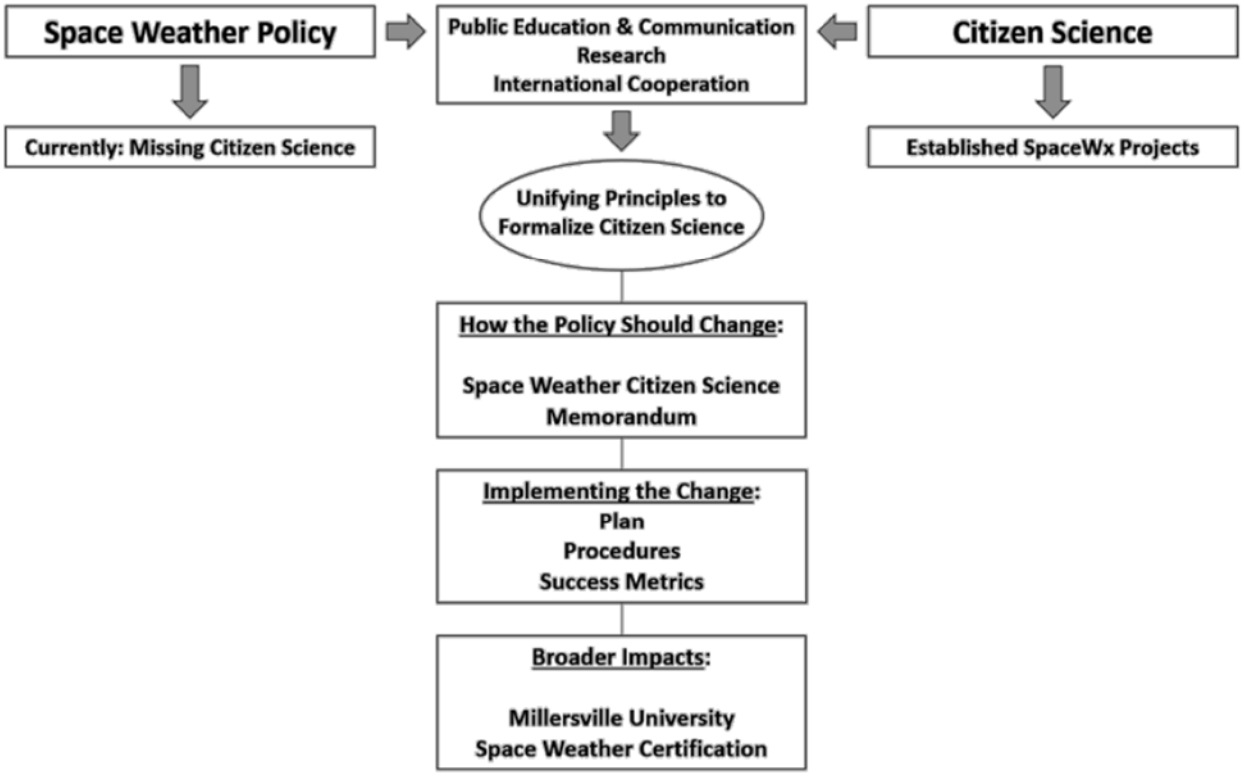

Figure 2. This flowchart depicts how this study evolved and was built upon the unifying principles of Space Weather and Citizen Science.

The thesis herein involved a thorough review and study of current US Space Weather Policy. What follows below is the methodology, although it is also an outline for what follows in the remainder of this thesis document. Recall from the previous section that this Space Weather Policy involves three themes where Citizen Science could potentially help: public engagement and education, improved research capabilities, and improved international cooperation. These details were identified. Existing Citizen Science Policy and ongoing projects were then investigated. The goal was to identify the unifying principles between these two fields (Space Weather Policy and Citizen Science).

Overall, there was a clear, desired approach in the Space Weather Policy regarding research, public engagement and international cooperation. Because good communication is so important for public engagement, peer reviewed articles and journal articles were then reviewed to provide insight into how difficult it is to communicate space weather to the public and the importance of being able to do so. The importance of being able to do so involves actionable steps to prepare for and recover from Space Weather events. The focus then turned to how real projects utilizing Citizen Science were accomplishing much of what the Space Weather Policy desired. Most of those examples came from journal articles but some came from the web. In particular, which Citizen Science projects were most successful in accomplishing Space Weather Policy, why those projects were successful and how these can shape future Space Weather Policy. Once exemplar projects were found, a plan was developed for a future Space Weather Policy involving Citizen Science, identifying procedures necessary to complete that plan, and defining metrics that would be indicative of a successful Policy. A plan for how future Space Weather Citizen Science projects should be designed is discussed as well as how they will be evaluated. This study will conclude with a broader impact that was discovered during this research.

CHAPTER III

ASSESSING POLICY & LAW BETWEEN SPACE WEATHER AND CITIZEN SCIENCE

Space Weather Review

This section analyzes all of the relevant Space Weather Policy. Space Weather Policy has been an evolving area as this field continues to grow in the public eye, as well as the threat it poses to our growing reliance on technology. Below will provide the necessary information about the current Policy surrounding the space weather community. It will examine what the Policy currently does well and what it lacks. The objective is to find common themes or goals that current Policy documents depict. That will be important to understand before the following section on citizen science, where the overlap will start to become apparent. An important distinction is knowing the difference between Policy and law. A Policy document is essentially a set of guidelines or principles a Government agency should follow but cannot be enforced as law. An executive order, two of which are analyzed below, can be enforced as law and is a directive from the President that manages operations of Government agencies.

National Space Policy of the United States of America[17]

This Policy document basically governs all of what we do in the space industry. The document is organized into sections as follows: introduction, principles, goals, intersector guidelines, and sector guidelines (commercial, civil, and national security). This is still the

[17] Obama, *National Space Policy,* 1 – 14.

current National Space Policy although it is from the Obama Administration. It has been modified in the current term of the Trump Administration in four issued space Policy directives. This document starts off by saying the space age mainly began between the United States and the USSR in a race for security and prestige. The introduction of this document immediately makes clear that the way we live our daily lives, has been vastly transformed due to the utilization of space. "Satellites contribute to increased transparency and stability among nations and provide a vital communications path for avoiding potential conflicts. Space systems increase our knowledge in many scientific fields, and life on Earth is far better as a result."[18] During natural disasters and relief efforts, we have seen how satellites have played a vital part in helping aid our mitigation and rescue operations. Along with the evolving technology and the economic development of other nations, there are more space-faring nations now than ever. With that said, the United States is committed to remaining the leading space-faring nation and will address the challenges that come with that.

One particular principle proposed in this document, could benefit from Citizen Science. "Space operations should be conducted in ways that emphasize openness and transparency to improve public awareness of the activities of Government, and enable others to share in the benefits provided by the use of space."[19] Another noteworthy principle mentions that space shall be used for national and homeland security activities. It will be shown later how other Space Weather Policy documents will do a better job going in-depth on this matter and why Space Weather poses a threat to national security.

Within the goals section of the US National Space Policy, a few directly relate to Space Weather and highlighted herein are areas where Citizen Science can be utilized. These include,

[18] Ibid, 1.
[19] Ibid, 3.

expanding international cooperation, protecting critical space infrastructure and improving space-based Earth and solar observations. This is another area in the document that provides an opportunity for Citizen Science to demonstrate how it can be useful.

The intersector guidelines – those guidelines that cut across, or intersect, multiple agencies - section of the US National Space Policy further motivates the thesis' purpose. "Departments and agencies shall conduct basic research and applied research that increases capabilities"[20] is one area that Citizen Science can impact. It could also impact the Policy guideline of "strengthening interagency partnerships." Because Citizen Science has shown to be a useful tool in public engagement and education, it would aid the US National Space Policy guideline to "implement measures to develop, maintain, and retain skilled space professionals, including engineering and scientific personnel and experienced space system developers and operators, in Government and commercial workforces."[21] Lastly, the document's guidelines of identifying areas for potential international cooperation, such as in the areas of earth science and observation and environmental monitoring[22], further invites Citizen Science into the solution.

Thus, the US National Space Policy provides many opportunities for Citizen Science to either be a solution or at least contribute even though the words "Citizen Science" are not mentioned. Below, the document review notes where Citizen Science has the potential to contribute.

[20] Ibid, 5
[21] Ibid, 6.
[22] Ibid, 7.

National Space Weather Strategy[23]

In October of 2015, two Space Weather documents were published together and were really the first of their kind. An updated strategy and action plan were released in 2019 and will be analyzed later in this chapter. The National Space Weather Strategy and National Space Weather Action Plan were both the result of interagency collaboration, which realized the increasing threat that space weather poses to our Nation's economic and social well-being. "Recent efforts led by the United States and its international partners have resulted in significant progress toward improving the understanding, monitoring, prediction and mitigation of this hazard, but much more needs to be done."[24] With that said, a task force was created to address these issues. The Space Weather Operations, Research and Mitigation (SWORM) Task Force was created in 2014 which led the charge in visioning what national preparedness of space weather would look like and how the United States would get there. This document states how Federal Government and agencies will engage academia as well as the public, on space weather.

In addition to the introduction and implementation sections, the strategy document highlights six goals that will reduce the Nation's vulnerability to space weather and all except #3 are relevant to the thesis herein:

1. Establish Benchmarks for Space-Weather Events
2. Enhance Response and Recovery Capabilities
3. Improve Protection and Mitigation Efforts
4. Improve Assessment, Modeling, and Prediction of Impacts on Critical Infrastructure

[23] John Holdren. National Science and technology Council. "National Space Weather Strategy," (2015). https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/final_nationalspaceweatherstrategy_20151028.pdf
[24] Ibid.

5. Improve Space-Weather Services through Advancing Understanding and Forecasting
6. Increase International Cooperation

The tone throughout this document and some of the themes stay consistent with the National Space Policy (e.g. improving research and international cooperation.) Regarding goal #1, establishing benchmarks[25] for space weather events is crucial because the effects of space weather can have impacts on both a local and global scale, and space weather phenomena and their effects must be measured to develop mitigation procedures that are appropriate to the threat/risk. Under this goal, the document mentioned the need for publically available data. Citizen Science projects are designed to produce and share valuable data with the public to provide transparency and connect the public with Federal agencies.

Goal #2 is intriguing because it calls for finding unique solutions to enhance the Nation's response and recovery capabilities to severe Space Weather events. Citizen Science projects are very unique in the way they leverage existing technology. Ongoing projects, such as Aurorasaurus, have demonstrated their ability to disseminate Citizen Science based alerts. One objective under goal #2 states to "develop and conduct exercises to improve and test government and industry-related space weather response and recovery plans."[26] This objective would be the ideal time to see if and how Citizen Science can contribute to disseminating information and aiding in response and recovery plans.

Under goal #4, one objective specifically states to "improve operational impact forecasting and communications."[27] It also calls for the ability to disseminate information as

[25] The document defines benchmarks as "a set of characteristics and conditions against which a space weather event can be measured. They provide a point of reference from which to improve the understanding of space weather effects, develop more effective mitigation procedures, enhance response and recovery planning and understand risk.
[26] Ibid, 7.
[27] Ibid, 8.

quick as possible to system operators and emergency managers relating to extreme space weather effects. An ongoing Citizen Science project that will be discussed later in this chapter, highlights how it is helping improve space weather models as well as delivering Citizen Science based alerts.

Addressing goal #5 listed above, Citizen Science could again help. The document calls for "adequate and sustained real-time observations for space weather analysis, forecasting and decision-support services."[28] When it lists where those observations will come from however, it does not mention Citizen Science, which has demonstrated the ability to provide real-time data throughout various STEM disciplines and projects. Utilizing existing Citizen Science projects as well as designing more to help fundamentally understand space weather and its drivers, will be imperative to improving predictive models.

Goal #6, which overlaps a goal in the US National Space Policy, is 'Increasing International Cooperation.' Citizen Science is not exclusive to the United States; many nations around the world also promote and utilize Citizen Science. "Countries around the world must work together to foster global collaboration, taking advantage of mutual interests and capabilities to improve the situational awareness, predictions and preparedness for extreme Space Weather."[29] Since a lot of Citizen Science projects already have participants from all over the world, some involving Space Weather, this seems like a natural opportunity for interagency and international collaboration.

[28] Ibid, 9.
[29] Ibid, 10.

National Space Weather Action Plan[30]

This Action Plan was released to implement the national goals laid out in the National Space Weather Strategy. Throughout this document, expected actions from a network ranging from the Government, agencies, emergency managers, academia and many more, are discussed. While the document never specifically mentions utilizing Citizen Science data, something that could chance in future Policy.

Recall from the Strategy document that the first strategic goal is to establish benchmarks for so-called "extreme space weather events" (defined as having a minimum recurrence interval of once per 100 years) and this begins with a two-phase approach. Phase 1, where Citizen Science may be able to contribute, is a quick turnaround utilizing existing data sets and studies to develop benchmarks. Phase 2, a more rigorous analysis, is where Citizen Science could thrive if projects were developed or existing projects were tailored, to help contribute in crafting these benchmarks. The document mentions several important benchmark space weather measurements that are associated with adverse effects that would be needed. These include but are not limited to the following: amplitude of the geo-electric field induced by geomagnetic storms - capable of adversely affecting power grids; amount of ionizing radiation near Earth - capable of affecting human health; total electron content in the ionosphere and disturbances therein - capable of adversely affecting radio signals; the wavelength and power flux of solar radio bursts - capable of adversely affecting radar, communication, and tracking signals; and solar-driven thermal expansion of the upper atmosphere – capable of shortening the lifespan of low-Earth-orbiting satellites.

[30] John Holdren. National Science and Technology Council. "National Space Weather Action Plan," (2015). https://www.sworm.gov/publications/2015/swap_final__20151028.pdf

The second strategic goal goes into detail on how to enhance response and recovery capabilities during extreme space weather events. Existing literature has proven how valuable Citizen Science data is during natural disaster and crisis management.[31,32] This document states the Department of Homeland Security (DHS) should assess the "dependencies and vulnerabilities of the various communications systems used by the Government and industry to support response and recovery operations in the wake of an extreme space weather event." Existing studies have proven that Citizen Scientists have observed changes in High-Frequency radio communications during space weather events.[33] This is noteworthy because Emergency Responders utilize High-Frequency radio communications.

The fourth goal in this document highlights the need to improve assessment, modeling and prediction of impacts on critical infrastructure. This is essential because of the threats that space weather pose on the electric power grid, aviation and GPS systems. The DHS and Department of Commerce (DOC) are instructed to identify gaps in current modeling capabilities. The Aurorasaurus project has already worked with the DOC and compared their Citizen Science data to the Oval Variation, Assessment, Tracking, Intensity, and Online Nowcasting (OVATION) Prime model, which helped assess the accuracy of this product.[6] In efforts to improve forecasting lead-time and accuracy, this document states that the National Aeronautic and Space Administration (NASA), the DOC, Department of Defense (DOD) and the National Science Foundation (NSF) should identify needs for improving space weather observations, particularly coverage and data. The deliverable item suggests a report with priorities and

[31] Paul Earle. "OMG Earthquake! Can Twitter improve earthquake response?," *Seismological Research Letters* 81, no.2 (2010): 207 – 285. https://dl.acm.org/citation.cfm?id=3217900
[32] Jeannette Sutton. "Emergent uses of social media in the 2007 Southern California wildfires." (2007). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.156.9517&rep=rep1&type=pdf
[33] Nathaniel Frissell. "Ionospheric Sounding Using Real-Time Amateur Radio Reporting Networks." *Space Weather* 12, no. 12 (2014): 651 – 656, doi.org/10.1002/2014SW001132.

recommendations. This would seem like a time to point out how Citizen Science can contribute with a vast range of coverage and quality data. These same departments/agencies minus the DOC are directed to identify and support basic research opportunities that enhance fundamental understanding of space weather and its drivers to develop and continually improve predictive models. Again, this appears to be another opportunity for Citizen Science to thrive and deliver what is being called upon to help improve the space weather field while simultaneously educating the customers and public.

Space weather is unique in the sense that the impacts range far and wide, with many nations agreeing that space weather is a global challenge. With that in mind, other nations besides the U.S. are also developing and strengthening their standards for protecting important infrastructure. This Action plan acknowledges the international efforts that are ongoing and highlights where there can be further collaboration. One objective states "Increase engagement with the international community on observation infrastructure, data sharing, numerical modeling and scientific research."[30] The Department of State (DOS), DOC and DHS along with other agencies are responsible for educating other nations about space weather and the threat it poses. Citizen Science projects have demonstrated international participation amongst projects so this seems like another area where Citizen Science can further contribute. International agencies can collaborate and keep other nations in the loop on existing projects and future space weather related projects that may be developed. Overall, this action plan does a very fine job highlighting what departments and agencies are responsible for, which provides valuable insight to where possibilities of utilizing Citizen Science lie. It does fail to recognize Citizen Science or Crowdsourcing, which seems to be a common theme in Space Weather Policy.

Executive Order -- Coordinating Efforts to Prepare the Nation for Space Weather Events[34]

Released by the Obama administration in 2016, this Executive Order reiterates the Policy requirement that the Federal Government predict and detect a space weather event and defines the agencies responsible for preparations. Recall from the introduction of this thesis that there are four primary types of space weather. Space weather phenomena range from solar flares which can affect radio communications and solar energetic particles that cause satellite anomalies. Geomagnetic storming, which is a result of coronal mass ejections or coronal holes, occurs regularly, as do the solar flares and solar energetic particles. Instances of extreme space weather can cause major damage to some of our key infrastructure. Significant space weather events can disable portions of the power grid which would have cascading effects. "Successfully preparing for space weather events is an inclusive endeavor that requires partnerships across Governments, emergency managers, academia, the media, the insurance industry, non-profits, and the private sector."[35] Ongoing Citizen Science projects have accomplished such, and also alert the public about an impending space weather event.[36]

Section two of the Executive Order reiterates these key objectives from the US National Space Policy: interagency collaboration, working with academia and looking for innovative ways to improve international cooperation. As is common of Executive Orders, roles and responsibilities are assigned to federal agencies and they have the force of law, which is why they differ from Policy documents. In this case, the roles and responsibilities "are key to

[34] Barack Obama. "Executive order – Coordinating efforts to prepare the nation for space weather event." (2016). https://obamawhitehouse.archives.gov/the-press-office/2016/10/13/executive-order-coordinating-efforts-prepare-nation-space-weather-events

[35] Ibid.

[36] Two Citizen Science Projects in the Space Weather field, Aurorasaurus and HamSCI, have proven how valuable they can be in contributing to observations and research in the Space Weather Field. They will be reviewed in detail later in the Citizen Science Review.

ensuring enhanced space weather forecasting, situational awareness, space weather preparedness, and continuous Federal Government operations during and after space weather events."[37] One agency of particular, the DOC, has already experimented in collaborating with Citizen Science. The National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center (SWPC) is responsible for providing space weather forecasts and real-time monitoring for the Government civilian and commercial sectors. DOC have used aurora observations that were submitted by citizen scientists for forecast model verification and improvements.[38] By doing that, they already are improving operational space weather services and utilizing partnerships, which is the second responsibility assigned to the DOC in this Executive Order.

This document then goes on to state that the administrator of NASA should also implement and support research to better understand our Sun, which produces space weather. By doing so, our models and forecasting capabilities will improve. That is then followed up with suggestions for more NSF supported fundamental research in the Space Weather field.

Overall, this document was useful in defining agencies and their responsibility in the space weather field. It echoed some of the same goals as the National Space Policy too. These goals and responsibilities of specific agencies are full of potential for Citizen Science. The Executive Order could have done a better job stressing the importance of building a space-weather-ready-nation by improving communications with the public in laypersons terms: to help the public learn the basics of space weather, its impacts, and risk. It also could have called upon agencies to utilize Citizen Science when it is relevant to their mission.

[37] Ibid.
[38] Case, *Using citizen science reports to define the equatorial extent of auroral visibility,* 198 – 209.

Space Weather Research and Forecasting Act[39]

The Space Weather Research and Forecasting Act bill was approved by the Senate Commerce Committee with bipartisan support but has not yet been signed into law. As discussed earlier in this thesis, bills differ from executive orders and policies in that bills must go through the entire legislative process. It must be approved by both houses of Congress and signed by the President, while an executive order does not need to go through the entire legislative process. This bill essentially directs specific agencies to exactly what their responsibilities are within the space weather field. The OSTP should improve the nation's ability to prepare for, respond to and recover from any significant space weather events. If this sounds familiar, that is because it is in line with the Executive Order issued under the Obama administration. The National Science and Technology Council are to establish the Space Weather Interagency Working Group which the OSTP will coordinate the efforts to understand, prepare and plan for possible space weather events. The bill touches on the collaboration between NASA and NOAA in terms of terrestrial weather observations and how a similar plan should be utilized in space weather. This was interesting to read because NOAA actively collaborates with Citizen Science projects[40] and again highlights the opportunity Citizen Science can provide to the space weather field. As of July 2019, the two main spacecraft that provide solar wind data are the Advanced Composition Explorer (ACE), which was launched in 1997 and the Deep Space Climate Observatory (DSCOVR), which is the follow on mission to ACE, was launched in 2015. Having only one long term satellite in DSCOVR, could be viewed as somewhat worrisome. This is why the

[39] Gary Peters. "Space Weather Research and Forecasting Act," (2019). https://www.congress.gov/bill/115th-congress/senate-bill/141
[40] Community Collaborative Rain, Hail & Snow Network. https://www.cocorahs.org/Content.aspx?page=aboutus

OSTP, in coordination with NOAA, NASA, the NSF and the DoD, are tasked to develop a plan for future solar wind observations beyond our current assets.

SOHO, is a very important space weather satellite as its coronagraph measurements give forecasters a way to analyze CME's erupting from the Sun. Although, this satellite is certainly past its prime and agencies must act quick to develop a backup plan. That is why this bill directs that NOAA, in coordination with the DoD and NASA, must develop at least one or more follow up projects for near real-time CME imagery. The NSF and the Air Force are tasked with providing space weather data by means of radio receivers and aurora imagers. This is already being accomplished throughout the Citizen Science community between HAM radio operators[41] and aurora field reporters[42]. Continuing with the NSF, this document states they should provide key data for research and model development in the space weather field. The Aurorasaurus project is actually a NSF-funded project and has demonstrated it can help with model development. NOAA, the Air Force and other relevant agencies, should conduct a survey that prioritizes the needs of space weather forecast users. This jumped out because a lot of space weather customers continue to learn that they are even affected by space weather. They need to be better educated so they can accurately prioritize their needs and communicate that in the survey. Citizen Science projects have demonstrated their ability to educate their participants[43,44] so this is another reason why Citizen Science could be incorporated into future Space Weather Policy. NASA and the NSF will make obtained space weather data available for forecasters and operation purposes, as well as support model development for space weather. Efforts like this

[41] Frissell, *Ionospheric sounding using real-time amateur radio reporting networks,* 651 – 656.
[42] Case, *Using citizen science reports to define the equatorial extent of auroral visibility,* 198 – 209.
[43] Jon Miller. "Americans and the 2017 Eclipse: An itnital report on public viewing of the August total solar eclipse," (2017). https://www.isr.umich.edu/cps/initialeclipseviewingreport.pdf
[44] National Academies of Sciences, Engineering, and Medicine. "Learning Through Citizen Science: Enhancing Opportunities by Design," (2018). https://www.nap.edu/read/25183/chapter/1

have been demonstrated with the collaboration between Aurorasaurus and the SWPC.[45] This bill builds on existing Space Weather Policy, and highlighted opportunity for Citizen Science but without issuing agency directives.

National Space Weather Strategy and Action Plan[46]

This document provides an updated version to the National Space Weather Strategy and the National Space Weather Action Plan from 2015 and was summarized earlier in this Policy review. With the new Space Policy directives made by the Trump administration[47] and the focus being human spaceflight exploration, this update to the National Space Weather Strategy and Action Plan (hereafter referred to as the Strategy and Action plan) provides an opportunity to advance the nations preparedness for space weather events. Three objectives are stated in the document:

1. Enhance the Protection of National Security, Homeland Security and Commercial Assets and Operations against the Effects of Space Weather.
2. Develop and Disseminate Accurate and Timely Space Weather Characterization and Forecasts.
3. Establish Plans and Procedures for Responding to and Recovering from Space Weather Events.

[45] Case, *Using citizen science reports to define the equatorial extent of auroral visibility,* 198 – 209.
[46] Kelvin Droegemeier. "National Space Weather Strategy and Action Plan," (2019). https://www.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf
[47] See Space Policy directives here: https://www.whitehouse.gov/presidential-actions/

The first objective mentioned in the Strategy and Action Plan calls for an assessment of how "critical infrastructure systems and national security assets" responds to space weather events. This includes the communications sector, where in September of 2017, a prime example emerged when extreme Solar Flares on the Sun disrupted High-Frequency radio communications.[33] National security comes into play, especially this event, because during the time High-Frequency radio was experiencing degradation, emergency responders were conducting Hurricane relief efforts.[48] The HamSCI Citizen Science project has demonstrated, multiple times, how it does a great job of assessing High-Frequency radio communication during space weather events. An area of opportunity is evident with how space weather can benefit from the utilization of Citizen Science, even though not specifically mentioned in this Policy.

One of the focal points for the second objective is to identify ground-based and air-based space weather observation platforms. What it does not mention, is the value in using ground-based observations of the aurora from the Aurorasaurus Citizen Science project and in monitoring the quality of HF Radio communications from the HamSCI effort. Another focal point emphasizes the importance of funding research in heliophysics and geospace sciences. It mentions that NASA and NSF are currently doing so but the field could further benefit from a targeted effort to encourage space weather Citizen Science projects. Validating and improving models is another area the Strategy and Action Plan identify as a need, along with identifying new or previously underutilized data sets. It is the thesis writers opinion that Aurorasaurus and HamSCI Citizen Science data sets are underutilized. Furthermore, space weather events known by scientists are not being conveyed effectively to operators, media and the public. That is why the Strategy and Action Plan calls for improving the effectiveness of space weather event

[48] Robert Redmon. "September 2017 Space Weather Impacts to Radio Communications During Hurricane," *Space Weather 16,* no. 9 (2018): 1190 – 1201. doi.org/10.1029/2018SW001897

notifications. The growth of smart phones, tablets and social media along with Citizen Science, serve an excellent platform to educate the public and other recipients of these notifications.

The Strategy and Action Plan aim to prepare a national and global response to space weather events. That is why one objective pertains to developing and disseminating information on potential effects from space weather events that will support response and recovery efforts. It is critical for the public, stakeholders and decision makers to understand the information that is being disseminated and receive it in a timely manner. Citizen Science and Crowdsourced data continues to have a growing role in disaster relief efforts.[49] Social media and Citizen Science are two platforms that could be utilized to ensure timely products and information are being disseminated and also a good platform to help communicate the potential effects and mitigation strategies. Overall, this updated version of the Strategy and Action Plan helps prepare the Nation for possible harmful space weather events. It also highlights numerous areas where the space weather field could benefit from the utilization of Citizen Science.

Executive Order on Coordinating National Resilience to Electromagnetic Pulses[50]

Two Executive Orders related to Space Weather have been issued under the last two administrations. First, there was the Executive Order under the Obama administration and now this Executive Order released by President Trump. This highlights how important Space Weather has become and why it is critical to give this field the proper attention. The focus of this

[49] Sultan Kocaman. "A Review On Citizen Science Applications For Disaster Management," *Int Arch Photog Rem Sens Spatial Inf Sci* 42, no. 3 (2018): 301 – 306. https://pdfs.semanticscholar.org/329b/f1e91d21ce0083c02431fac2fc6e64055778.pdf

[50] Donald Trump. "Executive Order – Coordinating National Resilience to Electromagnetic Pulses," (2019). https://www.whitehouse.gov/presidential-actions/executive-order-coordinating-national-resilience-electromagnetic-pulses/

Executive Order relates to EMPs and their ability to disrupt, degrade and damage critical infrastructure. There are two types of EMPs: Human-made and naturally occurring EMPs such as geomagnetic disturbances that are a result of Space Weather. "The Federal Government must provide warning of an impending EMP; protect against, respond to, and recover from the effects of an EMP through public and private engagement, planning, and investment."[50] It is important to have an attuned public because without it, preparing for, responding to and recovering from Space Weather events would be difficult.

It is stated numerous times throughout this Executive Order how important international cooperation is, a theme that has remained in all of the Space Weather Policy that has been reviewed. The Secretary of Defense and heads of other relevant agencies should provide operational observations of naturally occurring EMPs (geomagnetic disturbances). Accompanied by geomagnetic disturbances is the aurora, which the Aurorasaurus Citizen Science project collects real-time observations of the aurora. This provides an opportunity for collaboration between agencies and Citizen Science projects in future Space Weather Policy. The Policy states that the Secretary of Commerce should provide timely and accurate operational observations of naturally occurring EMPs (geomagnetic disturbances). They should also "use the capabilities of the Department of Commerce, the private sector, academia, and non-Governmental organizations to continuously improve operational forecasting services and the development of standards for commercial EMP technology."[50] Again, this seems like an effort that has already benefited from Citizen Science[6] but the Policy does not acknowledge or suggest Citizen Science as a possible solution. Lastly, agencies that support National Essential Functions should update their procedures and responsibilities to prepare for, protect against and mitigate the effects of EMPs. It

would be encouraging to see if any agency would consider using crowdsourced data as a tool for these procedures.

Space Weather Summary

A review of the relevant Space Weather Policy, bills and Executive Orders has revealed a few themes and narratives:

1. **Research**: Compared to terrestrial weather, space weather is still a relatively new and evolving field. That means there is a lot of research that still needs to be done to understand the complex system of our Sun. Research is needed when it comes to space weather phenomena, their impacts to our modern society and our ability to forecast space weather events. Current efforts in Research to Operations and Operations to Research are admirable but there still remains the need for more. Space weather research is a vast field but the main focus of the U.S. Policy is to really improve how space weather impacts can affect the public and the infrastructure.
2. **Public Engagement, Education and Communication**: Throughout a lot of the Policy, it is evident that understanding space weather impacts is critical. While understanding them is important, it is useless if the impacts cannot be properly communicated to the public and stakeholders. To take the necessary steps in being a "Space Weather-Ready Nation" the public, space weather customers and decision makers must be able to protect, mitigate, respond to, and recover from severe space weather events. These necessary steps cannot be taken if the stakeholders are disengaged, do not understand space weather or its impacts and cannot execute an actionable strategy. Heightening space weather

awareness is important, that is why public engagement, education and communication vital. It can also help motivate the public in participating in Citizen Science efforts.

3. **International Cooperation**: Space weather phenomena and their impacts are a global challenge that requires international support and collaboration. There are multiple levels and objectives when it comes to building international space weather support. The first task at hand is working with other nations who recognize space weather as a global challenge and who have policies that reflect that. Increased engagement and ongoing communication with international partners will advance observation capabilities, provide a broader database and hopefully lead to more data sharing which in return will further scientific research in the space weather community. More data, willingness to share that data and improved scientific research is wonderful but that is all futile if it cannot be used to improve space weather products and services. As the United States and other international states become very dependent on technology for everyday activities, there is a growing importance of having an international approach to preparedness for extreme space weather events.

Citizen Science Review

This section begins by reviewing a relevant piece of Policy regarding Citizen Science that was released through the White House OSTP. It will then examine Citizen Science as a whole, what the common benefits are from the field, and how federal agencies can implement it. Those common benefits include public engagement, education and communication, enhancing scientific research and the potential for international cooperation or collaboration. Then there will be an overview of some existing projects that are contributing to those common benefits in the space weather field.

Addressing Societal and Scientific Challenges through Citizen Science and Crowdsourcing[51]

This memorandum from John P. Holdren, former Director of the OSTP, back on September 30th, 2015. The memo outlines what Citizen Science is, how the Government might aid in public participation, who can benefit (including economic value), how the Government can determine effectiveness and what societal needs it might meet by advancing science, technology and innovation. This section herein will summarize the contents of that memo, and comment on what has happened since 2015.

First, this memorandum covers principles that agencies should utilize to maximize the use and effectiveness of Citizen Science. The memo specifically states that agencies should assign a Citizen Science coordinator and catalog agency-specific Citizen Science projects on an

[51] Holdren, *Addressing Societal & Scientific Challenges through Citizen Science & Crowdsourcing*, 1 – 11.

online Government website, to aid public participation in current projects in such a way as to contribute to an agency's mission and help bring that mission to reality. Note that the Multi-Agency Science and technology Priorities for the FY 2017 Budget also encourages Federal agencies to consider incorporating Citizen Science into their programs, as appropriate.[52] The directive outlined in that memo has since come to fruition in CitizenScience.gov.

Second, the Holdren memo states that Citizen Science can also have an economic value. For example, "after analyzing 338 Citizen Science biodiversity projects around the world, researchers estimated that the in-kind contributions of 1.3-2.3 million citizen scientists to biodiversity research have an economic value of up to $2.5 billion per year."[53]

While the Government can incentivize participation and demonstrate economic value, future success of the program depends upon the successful science projects. The Holdren memo outlines three areas of focus to be usied in determining how effective the Citizen Science project will be: data quality, openness and public participation. First off, the data collected by the public needs to be credible and the data made available to them needs to be usable and shareable. Each project is unique and thus should be treated as such, the "one-size-fits-all quality-assurance approach will not work for all projects."[54] Data-quality testing, management and project evaluation, all things a general science project would have, apply to Citizen Science projects as well.

The Holdren memo states that data is a valuable asset not only to Federal agencies but its partners and the public. "Data worth collecting and using also are worth preserving and

[52] Shaun Donovan. "Multi-Agency Science and Technology Priorities for the FY 2017 Budget," *Executive Office of the President of the United States.* (2015).
[53] Theobald, *Tapping the Unrealized Potential of Citizen Science for Biodiversity Research,* 236 – 244.
[54] Holdren, *Addressing Societal & Scientific Challenges through Citizen Science & Crowdsourcing,* 2.

sharing."[55] Citizen Science is a unique way to connect the Government with the public and in return that improves the Government's decision making. Citizen Science projects should acknowledge the public's participation and educate them on exactly how meaningful their contributions are to the project and broader impacts. For example, if results from a project are published, the participants should be acknowledged and notified of the results. Speaking of the Citizen Science community, these projects are also a wonderful opportunity for international cooperation between agencies and their similar projects. After all, many projects have participants from all over the world, trying to address local and global challenges.

The Holdren memo also states that another way for federal agencies to improve their use of Citizen Science is to "identify an agency coordinator for Citizen Science and crowdsourcing projects."[56] The Citizen Science coordinator is responsible for tracking and cataloging all Citizen Science efforts their agency supports on a Government website that has since been turned into CitizenScience.gov. "To increase interagency coordination, the coordinator will work with both the White House Office of Science and Technology Policy (OSTP) and other Federal agencies through the Federal Community of Practice for Crowdsourcing and Citizen Science (CCS), the National Science and Technology Council (NSTC), and other interagency working groups, as appropriate, to participate in future Policy-development discussions on this subject."[57] The Citizen Science coordinator should strategize how Citizen Science can help their agency fulfill their mission or reach their goals. In doing so, this will heighten awareness about Citizen Science and will hopefully lead to overcoming any Policy barriers that may exist at their agency.

[55] Ibid, 2.
[56] Ibid, 2.
[57] Ibid, 3.

If agencies want to be serious about incorporating Citizen Science into their mission, Policy is a critical first step. Citizen Science needs to be built into the Policy to enable project design (developed via open innovation toolkit)[58], procedures, guidelines, etc., as well as making sure legal issues are addressed like data collection, privacy acts, and other ethical issues. The second step is allocating resources and staffing to Citizen Science so the program can succeed. Third, includes investing in the proper technology and scientific instrumentation any project may need. The next step includes diversifying Citizen Science efforts and who is awarded funding. These opportunities should not only be available for large universities or contractors, include smaller communities.The last step involves consistently evaluating the projects. A few examples include improving the data collection and quality assurance process and how they are applicable to their agencies mission. NASA has since released a valuable document on how to evaluate Citizen Science proposals and ongoing projects that will be discussed in a later chapter.

This memorandum has shown the platform that Citizen Science offers, not only in terms of research, but for engaging the public in a unique way. It provides a starting point for agencies to begin implementing Citizen Science into their mission and disciplines. While this is only Policy and cannot be enforced as law, the benefits of Citizen Science demonstrate that an agency would be wise to allocate staff and funding to Citizen Science.

[58] The OSTP suggests that agencies utilize an open innovation toolkit to support Citizen Science project design.

The Benefits of Citizen Science in Research, Education and Community Engagement[59]

Citizen Science projects, as well as peer-reviewed research papers resulting from these projects, continue to increase.[60] This paper by Roetman et al suggests that projects can be created to address a wide range of issues, whether on a global or local scale. These projects benefit the scientists, the community and the decision makers which is further evidence that supports Citizen Science being involved in Space Weather Policy. Table 1 highlights a few Citizen Science projects and what they have contributed to research. "Undoubtedly the best way for the public to understand and appreciate the science is to participate in it."[61] Two different types of learning can occur participating in Citizen Science projects, informal and formal learning. The Aurorasaurus project showed a good example of informal learning through their Twitter community, Reddit AMAs and their scientist network.[62] This specific paper, felt their project was ideal for formal education and is why they chose to engage schools. Citizen Science projects have begun engaging schools and incorporating their projects into classroom learning.[63]

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[59] Philip Roetman et al. "The benefits of citizen science in research, education and community engagement," *Creating sustainable communities in a changing world,* (2011): 249 – 260. https://www.researchgate.net/profile/Philip_Roetman/publication/323998166_The_benefits_of_citizen_science_in_research_education_and_community_engagement/links/5ab7a760a6fdcc46d3b7f70e/The-benefits-of-citizen-science-in-research-education-and-community-engagement.pdf

[60] Cathy Conrad et al. "A Review of Citizen Science and Community-based Environmental Monitoring," *Environmental monitoring and assessment* 176, no. 1-4 (2011): 273-291. https://link.springer.com/article/10.1007/s10661-010-1582-5

[61] Johnathan Silvertown. "A New Dawn for Citizen Science," *Trends in ecology and evolution* 24, no. 9 (2009): 467 – 471. https://doi.org/10.1016/j.tree.2009.03.017

[62] Elizabeth MacDonald et al. "Aurorasaurus: A citizen science platform for viewing and reporting the aurora." *Space Weather* 13, no. 9 (2015): 548 – 559. https://doi.org/10.1002/2015SW001214

[63] Kathryn Paige et al. ""It felt like real science!" How Operation Magpie enriched my classroom," *Teaching Science: The Journal of the Australian Science Teachers Association* 56, no. 4 (2010).

Table 1. A selection of citizen science projects

Project	Notes
Wells Cook's collection of bird migration data	Wells Cook began a project collecting bird migration data in North America that ran from the 1880s to the 1950s and collected around 6 million records (Droege 2007)
Christmas Bird Count	Run by the Audubon Society, this project began in North America in 1900 with 27 observers. In 2006 there were over 57,000 participants (LeBaron 2007)
Project BudBurst	This project focuses on plant phenology in North America and had 4861 observations submitted during its first full year (Henderson and Havens 2009)
The Breeding Bird Survey	Run by the British Trust for Ornithology, this project included bird surveys at 3239 locations during 2010 (Risely *et al.* 2011)
Blackawton Bees	Run by the Institute of Ophthalmology, University College London, in association with Blackawton Primary School, this project investigated visual recognition of a bee species and experimental design (Blackawton *et al.* 2011)
Waterwatch	A water monitoring program in Australia, this project had over 15,000 individuals monitor 5000 sites (Thomson 2007)
GLOBE at Night	A light pollution project, has had participants in 86 countries (Gurton 2007)
Galaxy Zoo	A galaxy classification project, this project has had over 200,000 people involved (Raddick *et al.*2009)

Table 1. A selection of Citizen Science projects and what they do (from Roetman, 2011).

Roetman et all raise an important question; how can one tell if a participants interest and understanding in science has increased? That is a tall order according to one NSF-sponsored study.[64] Another study found that it may be difficult to increase science knowledge because the participants already have high level science knowledge.[65] That may have been true in 2007 when the paper was published but smartphones, tablets, and social media technology have improved both public inclusion in such projects and data accessibility, allowing almost everyone to be able to participate in these projects at any time from the tip of their fingers. The projects discussed in this specific paper concluded that "Our engagement of participants has led them to become more interested in, and increased their knowledge about, local wildlife"[59]. In terms of research, education and public engagement, there still seems to be a vast number of positive outcomes in terms of utilizing Citizen Science.

[64] Sue Allen et al. "Framework for evaluating impacts on informal science education projects," *In Report from a National Science Foundation Workshop*. (2008).
[65] K. Ellenbogen. "Evaluating citizen science: examining the goals of citizen science," *Proceedings of the Citizen Science Toolkit Conference, Cornell laboratory of Ornithology, Ithaca.* (2007): 83 – 88.

Aurorasaurus: A Platform for Real-Time Auroral Visibility

Figure 3. Logo from the Aurorasaurus project utilizes Citizen Science to nowcast Auroral Visibility.

This section is going to review the ongoing Space Weather Citizen Science project known as Aurorasaurus. It will provide an introduction about the project and Citizen Science, what the project does and what has it contributed to the Space Weather field.

Introduction:

A growing, space weather-based Citizen Science project called Aurorasaurus was developed to serve as an aurora observing and reporting platform. The primary goal of this project is to utilize crowdsourced data from the general public and their auroral observations as a way to further improve the modeling of the aurora. Aurorasaurus is also capable of providing a real-time auroral visibility map with the combination of citizen science reports and NOAA's aurora forecast model. "Aurorasaurus provides easily understandable aurora information, basic gamification, and real-time location-based notification of verified aurora activity to engage citizen scientists."[66] An objective of Citizen Science, one that Aurorasaurus is demonstrating, is that small amounts of volunteered time from a large number of people can contribute to a larger goal.[67] In the field of astronomy, many well-established Citizen Science projects are ongoing due

[66] MacDonald, *Aurorasaurus: A citizen science platform for viewing and reporting the aurora,* 548.
[67] Clay Shirky, *Cognitive surplus: Creativity and Generosity in a Connected Age* (Penguin, UK, 2010).

to the large group of amateur astronomers. The same cannot be said in the field of solar-terrestrial physics or space weather.[68]

Aurorasaurus has tapped into our ever growing technology and utilizes the advancements made in photographic equipment. For example, easy-to-use cameras that have long exposure capabilities are able to capture subvisual aurora that normally would not be visible to the naked eye. With the evolution of smartphones and digital photography along with social media, aurora hunters love chasing the northern lights and sharing them on their social media. Space weather and aurora in particular, are global phenomena, which means a large amount of people from all over the world can contribute. Aurorasaurus and this paper highlight a great point, Citizen Science is low hanging fruit where the new technological tools and advancements can be exploited for good use.

What is Aurorasaurus?

The main objective of this project is to utilize Citizen Science reports of the aurora to improve the ability to nowcast auroral visibility. While having a science driven objective, Aurorasaurus also educates the general public about the aurora, as well as space weather. Aurorasaurus offers another useful tool that can be useful during natural disasters, it is essentially a test bed for Citizen Science-based alerts. This ability of Citizen Science-based alerts is noteworthy because the National Space Weather Action Plan and Strategy emphasizes the ability to prepare for, mitigate and respond to space weather events. To help participants see the aurora, this project combines the science (the OVATION prime model via NOAA) and crowdsourced reports, to create their real-time aurora visibility map. The observational data is

[68] Delores Knipp. "Space Weather and Citizen Science," *Space Weather* 13, no. 2 (2015): 97 – 98.

collected in two ways: 1) website or free mobile app submission by Citizen Scientists who previously signed up with Aurorasaurus and 2) an automated scan and collection of aurora-related tweets by all Twitter users, regardless of the Twitter users' awareness of Aurorasaurus.

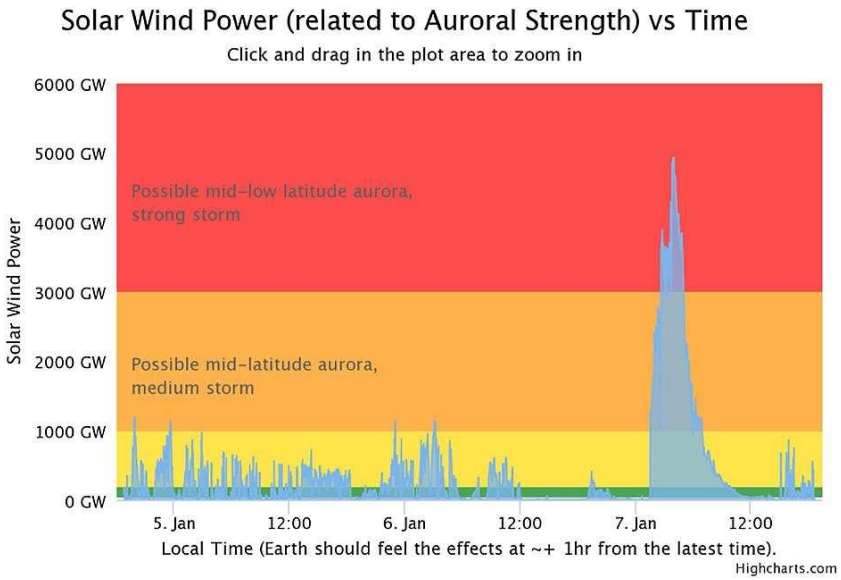

Figure 4. An example of the solar wind power plot on the Aurorasaurus website (Credit: Aurorasaurus).

Participants who are signed up on the Aurorasaurus project benefit from their real-time aurora alerts. These alerts are sent via e-mail and Twitter direct messages and provides the user with situational awareness when aurora may be visible near them. "If a certain number of positive sightings are reported in a localized area, which we term a positive cluster, any users located inside that cluster are informed that the aurora has been seen nearby."[69] Not only does Aurorasaurus alert its participants, it educates them as well. Communicating Space Weather is not an easy task. The forecasting capabilities are still evolving and communicating the phenomena and their impacts to multiple customers can also pose a challenge. "Aurorasaurus aims to provide clear and low-jargon information about when, and where, an aurora is visible."[70]

[69] MacDonald, *Aurorasaurus: A citizen science platform for viewing and reporting the aurora,* 552.
[70] Ibid, 553.

There are numerous ways scientists describe measurements of geomagnetic activity (e.g., Kp, Ap, Dst, or AE) but to make an effort in simplifying the science, Aurorasaurus adopted a "solar wind power" plot to communicate the auroral strength.[71] Figure 4 shows an example of the Solar Wind Power and demonstrates that it can be expressed in the units of power (GW), a concept the general public is familiar with. "Space plasma physics is not taught in most schools, including colleges, and most practioners only enter the field in graduate school."[72] This project has also adapted to the modern society and utilize social media platforms (Reddit AMAs, Google+ Hangouts and Tweet Chats) to have interactive discussion and Q&A sessions with the members of the project. Members from the Aurorasaurus team also write educational blog posts that are a little more in-depth for the space weather and aurora enthusiasts who may have some formal science background or are self-taught.

Relevance to Space Weather

Aurorasaurus is able to contribute to the space weather field in multiple ways but two really stand out because they are relevant and consistent to what Space Weather Policy is looking for. This project can assist with improving auroral oval forecast models by providing ground truth observations and data (research) and serve as a unique way to provide hands on STEM learning while educating the public about space weather (public engagement, education and communication). OVATION Prime[73] is probably the most well-known auroral oval model and in the next section, it will discuss how Aurorasaurus has contributed to improving that model. Like all models, the current auroral oval models have their shortcomings. These models lack real-time

[71] S.-I. Akasofu. "Energy Coupling Between the Solar Wind and the Magnetosphere," *Space Science Reviews* 28, no. 2 (1981): 121 – 190.
[72] MacDonald, *Aurorasaurus: A citizen science platform for viewing and reporting the aurora,* 554.
[73] P. T. Newell et al. "OVATION Prime-2013: Extension of auroral precipitation model to higher disturbance levels." *Space Weather*, 12 (2014): 368 – 379. doi:10.1002/2014SW001056.

data for validation and rely on data from the aging satellite, ACE. This topic is important for space weather research-to-operations needs including scintillation and spacecraft charging.[74] The data and observations being generated by Citizen Scientists on the Aurorasaurus project provides important parameters such as time, location and details of the aurora. Having numerous participants at different locations provides the opportunity for new auroral features or insights that would have not been possible by satellite. "Space scientists need to know the global distribution and evolution of different types of aurora during storms to quantify the energy budget for these storms."[75] Overall, the value of projects like Aurorasaurus is evident and the next section will cover some of the accomplishments this project has been able to contribute to the Space Weather field so far.

Accomplishments

One of the unique features the Aurorasaurus project offers, is the ability to send out aurora alerts to their participants. The project is serving as a proof-of-concept for alert and early warning notifications that could be extremely valuable during natural disasters. This is also of note because the National Space Weather Strategy and Action Plan recognize how important it is for the Nation to be able to prepare for, respond to and recover from Space Weather events. The projects ability to utilize real-time data by converting that into nowcasts and alerts is an important element, especially in an early warning system. "Our early results from our beta phase point to potential success in combining both algorithmic and participant filtering of social media data into faster more accurate nowcasts" [76] Early warning systems are essential during natural

[74] Y. Zheng. "Report on Study of Auroral Oval Boundaries, Modeling Challenges in Auroral Region," *GEM Mini-Workshop*, Portsmouth, VA. (2014).
[75] MacDonald, *Aurorasaurus: A citizen science platform for viewing and reporting the aurora,* 555.
[76] Andrea H. Tapia et al. "AURORASURUS: Citizen Science, Early Warning Systems and Space Weather," *Second AAAI Conference on Human Computation and Crowdsourcing*, (2014): 30-32.

disasters but it is difficult to know or track if the alert or message that was sent out was actually acknowledged or acted upon. Aurorasaurus is actually able to track the path of a notification. "If they receive it, then contribute to a positive or negative sighting, we can know that the notification was received and acted upon."[77]

Aurorasaurus worked on a study with the SWPC to compare 500 Citizen Science reports with the view line provided by the OVATION Prime (2013) model.[78] The "view line" refers to where an aurora may be visible. This is the SWPC official aurora forecast product and until this study, no extensive testing was conducted to determine how accurate the view line was. The data in this study was collected by Aurorasaurus participants and positive sightings on Twitter that Aurorasaurus members verify, during the months of March and April 2015. The study concluded that the SWPC view line accuracy was poor and the results warranted further investigation into the scaling parameters used in the view line calculation.[79] After modifying the scaling parameters, the accuracy of the view line more than doubled. While there are caveats to every study, the clear message in this particular case is that Citizen Science reports have the ability to provide ground truth observations for models which in return can improve the ability to forecast Space Weather. It is stated throughout Space Weather Policy, particularly the National Space Weather Strategy and Action Plan, that the DOC (SWPC) should improve their modeling capability and observational data. It seems that the Aurorasaurus project demonstrated the ability to do both, which further emphasizes the value of Citizen Science in Space Weather going forward.

[77] Ibid, 32.
[78] Case, *Using citizen science reports to define the equatorial extent of auroral visibility,* 199.
[79] Ibid, 207.

Solar Maximum, which peaked in 2014, was really the first Solar Maximum where the public had near scientific-grade digital cameras and smart phones that were able to observe the aurora. Between better cameras, more space weather publicity and the help of Citizen Science, "photographers recently reported repeatedly observing a dynamic, very thin, east-west-aligned aurora-like structure significantly equatorward of the auroral oval during enhanced activity."[80] In the past, auroral features like these have been known as Proton Arcs. But Proton Arcs are subvisual, broad and diffuse.[81] The feature that Citizen Scientists were reporting was quite different, it was visually bright, narrow and structured. It was also being seen at lower latitudes compared to where Proton Arcs typically manifested. A pattern began to develop of when this auroral feature was being observed:

1. Enhanced auroral activity.
2. Often seen over the Alberta, Canada region.
3. Observed during premidnight hours.
4. Lasted about an hour.

The Citizen Science and social media community that were observing and discussing this auroral feature gave it the name of "Steve" and later in 2016, a backronym was formed, "Strong Thermail Emission Velocity Enhancement" (STEVE).

STEVE is unique in the way the discovery happened. It was a combined effort of Citizen Scientists, ground based all-sky imagers and satellite measurements. "The STEVE structure was also observed by one of the University of Calgary all-sky imagers between 05:48 and 07:10 UT

[80] Jacey Fortin. "That Ghostly, Glowing Light Above Canada? It's Just Steve," *The New York Times*, (2017).
[81] R.H. Eather. "Auroral proton precipitation and hydrogen emissions," *Reviews of Geophysics* 5, no. 3 (1967): 207 – 285 (1967).

on July 25th, 2016."[82] The European Space Agency launched a constellation of satellites in 2013 known as Swarm. Lucky enough, Swarm A actually passed through the STEVE structure and recorded measurements as well on July 25th, 2016. This is noteworthy because of how it ties into Space Weather Policy. It is referenced in the National Space Weather Action Plan and Strategy[83] how important it is to identify ground-based and air-based space weather observation platforms. In this situation, both observation platforms are used to discover a new auroral feature and Citizen Science played a critical role. Not only that, this demonstrates a case study where international cooperation played a role. Citizen Science demonstrated it can contribute valuable data and also help facilitate opportunities of international cooperation.

[82] MacDonald, *New Science in Plain Sight*, 2.
[83] Droegemeier, *National Space Weather Strategy and Action Plan,* 2019.

HamSCI: The Ham Radio Science Citizen Investigation

Figure 5. HamSCI was started by ham-scientists who study upper atmospheric and space physics.

This section reviews the ongoing Space Weather Citizen Science project known as HamSCI. It reviews the data collected, how it relates to Space Weather and its utility.

What is HamSCI?

HamSCI is an organization that aims to connect scientists with the amateur (Citizen Scientists) Ham radio community. Ham radio is a hobby for radio enthusiasts which includes communicators, builders and experimenters. When Ham Radio Operators transmit/receive high frequency radio communications, scientists can use an automated shortwave receiving network, called the Reverse Beacon Network (RBN), to observe and monitor these communications as a way of remotely sensing the ionosphere. HamSci aims to foster collaborations and communications amongst multiple projects and institutions.

Relevance to Space Weather

The ionosphere is a critical layer of our atmosphere when it comes to space weather. This region is critical because it reflects and modifies radio waves used for communication and navigation. Space Weather phenomena such as solar flares, geomagnetic storms and energetic particles are able to modify the ionosphere which in return can impact radio communication, radio navigation (GPS) and satellite communication. Observing and understanding how the ionosphere is important because of the particular operations that depend on this layer of the atmosphere. For example, emergency responders utilize HF radio communications which depends on the ionospheric conditions. Severe solar flares have the ability to completely wash out HF radio communications. Military operations also rely on radio communications and greatly care about how Space Weather could be affecting the ionosphere. HamSCI participants and data coming from these efforts provide a real-time observing platform for how the ionosphere is responding to Space Weather events.

Accomplishments

While there are instruments in place to help us measure the ionosphere in real time with things like ionosonde networks[84], GPS total electron count receivers[85] and satellite-based GPS occultation receivers[86] there are still challenges. Due to how dynamic the ionosphere is with local and seasonal variation as well as solar cycle dependence, this layer still remains under sampled.[87] A specific case study was done on the X2.9 solar flare on May 13th, 2013. This case study shows how the Reverse Beacon Network (RBN) and the GOES 15 spacecraft both

[84] B. W. Reinisch et al. "Recent advances in real-time analysis of ionograms and ionospheric drift measurements with digisondes," *Journal of Atmospheric and Solar-Terrestrial Physics* 67, no. 12 (2005): 1054 – 1062.
[85] William Rideout et al. "Automated GPS processing for global total electron content data," *GPS Solutions* 10, no. 3 (2006): 219 – 228.
[86] Anthea Coster et al. "Space weather and the global positioning system," *Space Weather* 6, no. 6 (2008): 1 – 6.
[87] Nathaniel A. Frissell, "Ionospheric Sounding Using Real-Time Amateur Radio Reporting Networks," *Space Weather* 12, no. 12 (2014): 651 – 656.

observed the solar flare. Figure 6(a,b) depict the HF propagation paths before the X-class flare occurred and shows a significant number (over 1100) of HF paths between Europe, North America, South America and Africa on frequencies from 7 to 28 MHz.[88] The solar flare happens to line up perfectly with Figure 6(c) and here it is noticeable how many HF paths disappear when the flare peaks at 1605 UT. A gradual recovery of the HF paths and different frequencies begins in Figure 6(d) which is at least 30 minutes after the peak of the X2.9 solar flare. Figure 6(e) shows the GOES 15 X-ray flux measured on May 13th, 2013 which lines up perfectly with the vanishing HF paths depicted in figure 6(c).

[88] Ibid, *Ionospheric Sounding Using Real-Time Amateur Radio Reporting Networks*, 655.

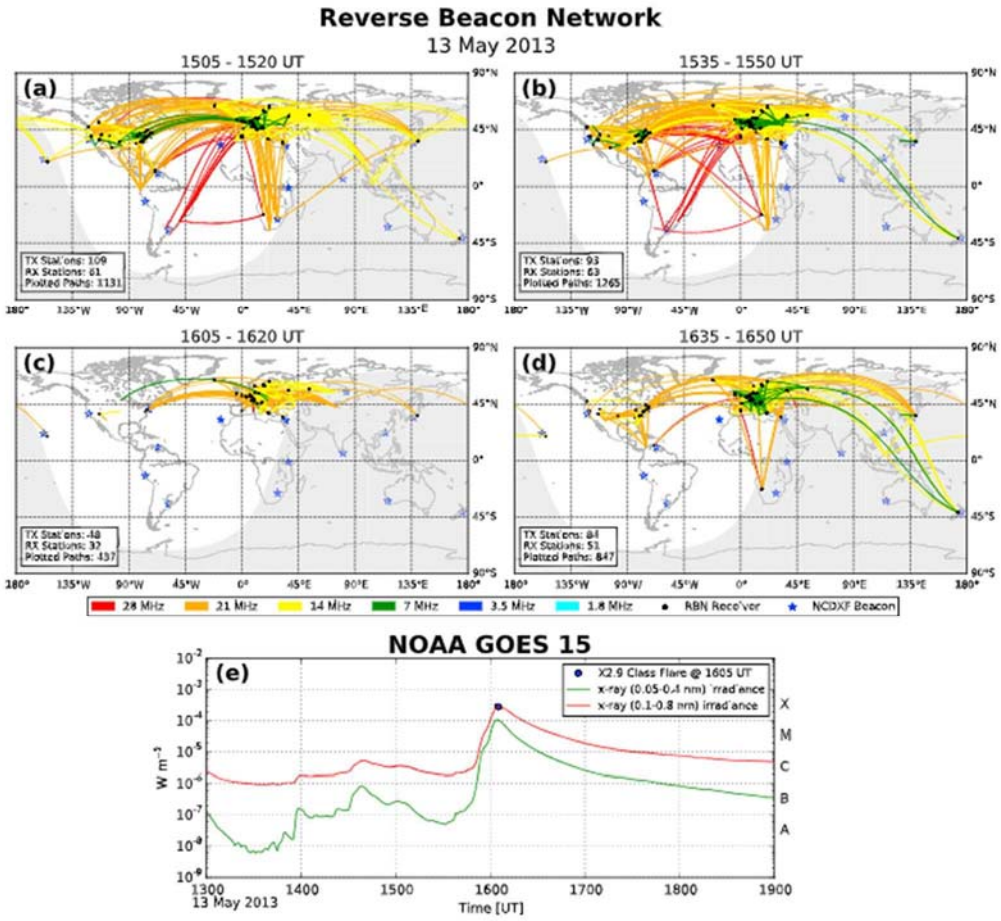

Figure 6. (a-d) RBN high-frequency observations from 13 May 2013. Paths are color coded by frequency. (e) GOES 15 X-ray flux measurements for 13 May 2013. The dot at 1605 UT indicates the X2.9 class solar flare that causes decrease in RB activity (from Frissell, 2014).

This case study provided is useful for multiple reasons. First, it demonstrates the usefulness of amateur radio reporting networks and how they are able to monitor and observe how the ionosphere responds during space weather events. Second, this is being done on a daily basis by citizen scientists (Ham radio operators in this instance), which shows how valuable citizen scientists can be in contributing to research but also as a real-time observing network. Third, this network could be used as a real-time resource for our emergency responders which is important as they rely on HF radio communications. This goes back to the National Space Weather Action Plan and being able to prepare for, mitigate and respond to space weather events. A future area where improvements could be made is comparing the amateur radio

observations to the NOAA D Region Absorption Predictions (D-RAP) model. This could serve as a ground truth comparison to what the model is suggesting, similar to what Aurorasaurus did with the NOAA OVATION Prime model.[89]

In August 2017, the total solar eclipse(whereby the moon completely passes in front of the Sun, shadowing a narrow path across Earth) traversed the Oregon coast to the South Carolina coast. These events are spectacular opportunities for the public to see something truly awe-inspiring but also a great opportunity to conduct ionospheric research. To study how the ionosphere changes during a total solar eclipse, ham radio operators communicated with each other before, during and after the eclipse on August 21st, 2017. HamSCI organized a large-scale Citizen Science experiment where over 5,000 ham operators participated and contributed to a large data set. The goal was to compare the data collected by the participants with outputs of an eclipsed version of the ionospheric research model SAMI3. "By comparing data with model results, we demonstrate a technique that relates amateur radio spot data to research-grade ionospheric models."[90] "This is the first eclipse-ionospheric study to make use of measurements from a citizen-operated, global-scale HF propagation network and develop tools for comparison to a physics-based model ionosphere."[91] The HamSCI effort is another example of Citizen Scientists contributing meaningful data to help improve the understanding of space weather and better the models all while providing hands on STEM learning. It is evident that Citizen Science can be utilized in the Space Weather field and should be included in future Space Weather Policy.

[89] Case, *Using citizen science reports to define the equatorial extent of auroral visibility,* 198 – 209.
[90] Nathaniel A. Frissell, "Modeling Amateur Radio Soundings of the Ionospheric Response to the 2017 Great American Eclipse," *Geophysical Research Letters* 45, no. 10 (2018): 4665 – 4674
[91] Ibid, 4673.

New Citizen Science Projects Funded for Earth Studies[92]

In 2018, NASA allocated $7.5 million over the next three years for six new Citizen Science projects. The projects will be providing local snow observations, global kelp cover, animal biodiversity, air quality reports and water storage in lakes. These projects, led by established researches, will provide the public with a chance to participate in data collection and Earth science research. Kevin Murphy, program executive for the Earth science data systems at NASA Headquarters in DC said, "The projects merge the public's enthusiasm in science with rigorous scientific methods necessary for understanding the global environment." As these six projects ramp up and mature, they'll be providing free, open access data to scientists around the world. The data gathered by the citizen scientists will also be used to improve NASA satellites. Most of these projects are linked to Universities across the country, which will also increase student participation and hopefully trickle down to the public. The six projects will just add another way to monitor our planet's natural resources and changing climate.

Citizen Science Summary

After reviewing the relevant Citizen Science Policy and projects, a few goals and directions became apparent:

1. **Address Societal Needs and Accelerate Science**: Citizen Science is a unique way to solve local and global scale issues. The public participates voluntarily while addressing real-world problems by collecting and analyzing data, examining the results and developing new applications or solutions to address complex problems. Citizen Science

[92] Kindra Thomas. "New Citizen Science Projects Funded for Earth Studies" last modified April 17, 2018. https://www.nasa.gov/feature/new-citizen-science-projects-funded-for-earth-studies

projects have shown to be useful in many ways, including making new discoveries, serving as a real-time alert system, providing more observations and improving scientific models. With that said, it is evident certain existing Citizen Science projects overlap with some of the Space Weather Policy goals and directions. Space Weather desperately needs more observations, more data and enhanced scientific understanding. There is a societal need to better understand local and global scale space weather impacts, Citizen Science seems like a good way to address that need.

2. **Education and Outreach:** These projects are designed to accomplish many things but arguably none is more important than the hands-on learning in science, technology, engineering and mathematics (STEM), that these projects provide. They also are connecting members of the community with Federal agencies and really teaching them about their mission, their goals and provide transparency into what they do. Connecting with the public is important for many reasons but one in particular is that a more educated public or community can than better understand how federal agencies are using science to address needs related to them. It is also important for the younger participants and getting them interested in a possible career in STEM. Educating the public or communities will provide them with a better understanding of issues that are surrounding their local community or global challenges. The hope would then be that this leads to an increased awareness and desire to help address these issues and possibly create a new generation of scientists and leaders.
3. **Local or Global Scale:** Citizen Science is applicable at a local and global scale, projects are very much inclusive rather than exclusive. This means that participants can collect data and contribute to a project that addresses a local need or help solve a global

challenge. There are numerous projects that are connecting different communities and that are helping diversify the STEM field. It is important to recognize because science is not just used to fix small scale, local issues, science is used to address global needs as well. Space Weather in particular is another example of their being local and global impacts. As noted above in the Policy summary, international cooperation was a common theme in most Space Weather Policy. Since Citizen Science has a global reach and impact, it would be beneficial to explore possibilities of having Federal agencies from other countries use Citizen Science as a way to collaborate and address global challenges such as Space Weather.

Chapter IV

HOW THE POLICY SHOULD CHANGE

Now that Space Weather Policy and associated relevant Citizen Science projects have been reviewed, it is time to examine what a future Policy document involving Space Weather and Citizen Science could look like. This is meant to serve as a suggested possible framework. First, a memorandum that outlines principles and directs agencies would be necessary and a great example of one that already exists was issued on behalf of John Holdren about Citizen Science.[93] Below is an example of what a space weather and Citizen Science memorandum could look like:

MEMORANDUM TO THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

FROM: Director of the Office of Science and Technology Policy

SUBJECT: Addressing Space Weather Communication and Research Challenges With Citizen Science

Overview

Citizen Science is an emerging field that, over the years, has shown its ability to address societal needs and advance science. A citizen scientist is an individual who voluntarily contributes his or her time, effort and resources toward scientific research in collaboration with professional scientists or alone. “Amateur science,” “crowdsourced science,” “volunteer monitoring,” and “public participation in scientific research” are also common aliases for Citizen

[93] Holdren, *Addressing Societal and Scientific Challenges through Citizen Science and Crowdsourcing*, 1 – 11.

Science. While Citizen Science projects are abundant and cataloged on a Government-wide online database (citizenscience.gov), projects in the field of space weather are somewhat rare.[94] With advancing technology and the capabilities of smart phones, it is clear that Citizen Science had been underutilized in the space weather field. Projects like Aurorasaurus and the HamSCI effort in the Space Weather field have demonstrated their value.

Existing Space Weather Policy has these themes: communication and engagement, research and international cooperation. All of these, have been contributed to and advanced by Citizen Science. Participants gain a lot of hands-on learning, whether that's informal or formal. It's also another way to inspire the next generation of professionals in the STEM field as well as connecting members of the public to federal agency missions. In recognition of these potential benefits, this memorandum encourages the use of Citizen Science in space weather by Federal agencies.

Specifically, this memorandum will:

1. Outline principles that Federal agencies' coordinator for Citizen Science projects can apply so they are maximizing the fullest potential of Citizen Science and working it into their agency's mission.
2. Direct the agency coordinator for Citizen Science to utilize the Government website (citizenscience.gov) to manage their agency's contributions and post all relevant information about any projects they support.
3. Identify areas within the space weather field where Citizen Science can contribute.
4. Discuss the challenges of Citizen Science and where it needs improvement.

[94] Knipp, *Space Weather and Citizen Science*, 97 – 98.

Principles for Effective Use of Citizen Science in Space Weather

It is important that each project an agency supports, that the projects goal or need is in line with their mission. In order to be able to support these projects, the agencies' coordinator for Citizen Science projects must work with management to include the projects in their budget. Once this is worked out, applying the following principles to project design will be crucial in maximizing the return from these Citizen Science projects:

- **Data quality**. This is one of the most common questions regarding Citizen Science, how does one ensure the data is credible? Project leaders need to recognize that a data quality plan must be developed for each individual project. Citizen Science projects should adapt the practices most scientist-lead science projects entail: data-quality assurance, data management, and ongoing project evaluation. Despite some skepticism, there seems to be a growing consensus that datasets produced by volunteer citizen scientists can have reliably high quality data, on par with those produced by professionals.[95]
- **Openness.** Projects should be designed to generate datasets that are machine-readable, based on open standards[96] and are understandable and applicable for users.[97] In order for these projects to be truly successful, not only must the data being collected be valuable to scientists, policy makers and disaster responders, but it needs to be useable and understandable for the participants. The openness of the data is also valuable for potential collaboration and even international cooperation. Different agencies or countries may see

[95] Margaret Kosmala et al. "Assessing data quality in citizen science." *Frontiers in Ecology and the Environment* 14, no. 10 (2016): 551-560. https://doi.org/10.1002/fee.1436
[96] An open-standard format is one which does not require proprietary software to be read.
[97] John Holdren. "Increasing access to the results of federally funded scientific research," *Office of Science and Technology Policy, Executive Office of the President.* (2013).

the potential for some joint-efforts, which is a goal in the National Space Policy and many Space Weather Policy documents.

- **Public engagement**. Citizen Science is a field accomplishing many things but is dependent upon public participation. People from all over the world participate in Citizen Science and each individual provides their own uniqueness and expertise. Beyond just getting participants involved with the projects, they should also be recognized for their contributions. Space weather and the impacts are much localized, it is important to ensure those local communities are engaged and knowledgeable so they want to participate in ongoing and future Citizen Science projects. The participants not only contribute valuable data but through hands these projects and hands on learning, they're being educated about a vastly growing field that impacts daily technologies. Agencies should engage other countries with similar goals to provide greater spatial coverage in space weather data and improve international cooperation to advance our understanding of space weather together.

Responsibilities for the Agency Coordinator for Citizen Science

There are currently 400+ Government agency sponsored projects cataloged on citizenscience.gov. This website was created by the General Services Administration as ordered from the Citizen Science memorandum in 2015.[98] To maximize the greatest value of this online catalog and public participation, agency coordinators for Citizen Science shall:

- **Improve Citizen Science marketing efforts towards the public**. With growing technology and usage of smartphones, the public is willing and eager to participate in

[98] Holdren, *Addressing Societal & Scientific Challenges through Citizen Science & Crowdsourcing,* 1 – 11.

unique opportunities. Within 90 days of the issuance of this memo, each agency coordinator for Citizen Science should come up with their own marketing strategy, to engage the public about Citizen Science and lead them to citizescience.gov so they can easily view all of the opportunities. Options such as creating infographics to engage followers on social media platforms should be explored. As well as any public outreach events for their agency; Citizen Science participation and education should be one of the focal points of the event. To evaluate each agency's strategy, the coordinators will work with the White House OSTP and assist in future Policy-development discussions on this subject.

- **Continue updating contributions of Federal Citizen Science projects**. To ensure the database of projects are up to date, agency coordinators should routinely update their projects on citizenscience.gov. Making this process as easy to navigate and use is important to encourage users to participate on a project. Ensuring all links work and are routinely updated, is critical to the projects recruitment, growth and success. The goal is to make it as easy as possible for volunteers to get involved. Routinely updating project information and status will help avoid duplicating projects or efforts among agencies. With that said, it also makes it clear what areas of space weather or science in general, are yet to have a Citizen Science project investigating a certain topic.

Future Areas in Space Weather That Could Benefit From Citizen Science

While there are some space weather Citizen Science projects doing great things, there are not many.[99] The science community is called upon to identify and prioritize scientific questions that need to be tackled and how that'll be accomplished. That is where the Solar and Space Physics Decadal Survey becomes important. The goal of these surveys are to map out a plan for at least the next ten years and clearly prioritize research areas, observations and how agencies will contribute. This survey reiterates up the importance of supporting "the nation's increasing need for information about Earth's near-space environment and space weather."[100] The current survey is for the 2013-2022 period and there is no mention of Citizen Science, crowdsourcing, etc. An ongoing study is an assessment of agencies implementation of the previous decadal survey and that will likely come out in 2020. The assessment will include many tasks but one of importance to Citizen Science is: "Recommend any actions that could be taken to optimize the science value of the Agencies' programs including how to take into account emergent discoveries and potential partnerships since the decadal in the context of current and forecasted resources available to them."

Federal agencies along with their coordinator for Citizen Science should identify areas in space weather where they believe Citizen Science is being underutilized or research topics that Citizen Science projects could address. Within 90 days of the issuance of this memo, each agency should submit their review of where future Citizen Science projects can contribute to areas of space weather to the Space Studies Board Committee. By doing so this will give the

[99] Knipp, *Space Weather and Citizen Science,* 97 – 98.
[100] National Academies Space Studies Board.
http://sites.nationalacademies.org/SSB/CompletedProjects/SSB_056864

board time to consider the importance of Citizen Science in the space weather field which then can be mentioned in the "Recommend any actions that could be taken to optimize the science value of the Agencies' programs…" midterm assessment. The Space Studies Board of the National Research Council should then draft a decadal study-request for information (RFI) from the community. Similar to the one released in 2010[101], this RFI will ask the members of the Solar and Space Physics Community to identify areas in space weather where Citizen Science could add scientific value and engage the public. Once areas of research are prioritized for Citizen Science in space weather, agencies should allow for the possibility of allocating funding and staff to Citizen Science.

Challenges of Citizen Science in Space Weather

Like in every aspect of science and life, there comes challenges and Citizen Science is no different. There are known challenges that come with Citizen Science like training and data management but also challenges in terms of Citizen Science with Space Weather such as education. Below are the main challenges that would need to be addressed to maximize the efficiency of Citizen Science in space weather:

- **Data management**. Working with Citizen Science, data management almost always proves to be one of the biggest challenges and through good project design and proper training, it can be quality controlled. "Participants contributing data to Citizen Science projects vary in age, experience, skill, training, willingness to be trained and other attributes that influence data accuracy."[102] Whether a project is just beginning or has been

[101] Daniel Baker et al. "Decadal Study-Request for Information (RFI) from Community," *National Academies*. (2010).
[102] Janis Dickinson et al. "Citizen Science as an Ecological Research Tool: Challenges and Benefits," *Annual review of ecology, evolution, and systematics* 41, (2010): 149 – 172.

ongoing, it is important to have guidelines suited to an individual project and these should be revisited to ensure they are adequate as the projects grow and develop. While more research into Citizen Science data management would help advance the field even more, agency coordinators for Citizen Science should review the Data Management Guide for Public Participation in Scientific Research.[103] Another topic that often arises with Citizen Science is data quality. There are many successful Citizen Science projects that have demonstrated how valuable their data is but particularly in space weather, the Aurorasaurus and HamSCI projects. With Citizen Science projects being scarce in the Space Weather field, there will certainly be a lot to learn about data management going forward.

- **Education.** Engaging and educating participants about Citizen Science is always a critical role to ensure maximizing participation and growing the project success. With most Citizen Science projects though, it is not a daunting task to engage and educate the public about a project that supports their local community or has to do with the environment on a global scale. Although, Space Weather is a completely unfamiliar concept compared to terrestrial weather. The public is able to visually see and experience terrestrial weather, they're able to understand how it affects their daily lives and activities. With space weather, that is not necessarily the case except for the visually stunning aurora that is localized to observers in the northern latitudes.

END OF PROPOSED MEMORANDUM

[103] Andrea Wiggins et al. "Data Management Guide for Public participation in Scientific Research," *Data One Working Group* (2013): 1 – 41.

Summary

The main driver of this example Memorandum is to get Federal Agencies to recognize what Citizen Science is and understand how it can contribute to Space Weather. Projects like Aurorasaurus and the HamSCI effort have proven the value of Citizen Science in the Space Weather field and highlight the opportunities they offer. The goal is to have agencies understand how Citizen Science can support their mission, as well as implement new projects their operation to supplement any existing projects. A concerted effort that is Policy driven will help maximize the utilization of Citizen Science in the Space Weather field. Once Federal Agencies understand how Citizen Science can support their mission, Citizen Science grant announcements of opportunity (AOs) could be a success criteria. This is an example of how Policy can shape Citizen Science projects and make them serve the needs of the Government and the community better.

CHAPTER V

IMPLEMENTING THE CHANGE

In the prior chapter, the draft of an example Memorandum on Citizen Science in Space Weather lays the foundation. That is the first step in creating a concerted effort amongst agencies to implement Citizen Science into their operation. Once a Memorandum encouraging agencies to utilize Citizen Science is released, they can begin developing a plan. That plan should include referring to the suggestions made in the Memorandum, as well as implementing them into their future Citizen Science project design. The next important step would be implementing procedures for future Citizen Science projects that will allow them to engage the public in a successful way and maximize participation. Lastly, defining success metrics for the Citizen Science projects are a must. There will need to be a way to determine how meaningful the project is in terms of what it is able to accomplish. This chapter will examine how agencies will develop a plan to implement Citizen Science into their missions, what procedures should be required for a successful project design and how they'll help meet the goals of Space Weather Policy, and define success metrics for Space Weather Citizen Science projects.

The Plan

Orchestrating a concerted effort to incorporate Citizen Science into the Space Weather field is the first and most important thing. Recently, NASA released their annual solicitation for basic and applied research. It is known as Research Opportunities in Space and Earth Science (ROSES) and has numerous individual programs with their own topics. Citizen Science is actually highlighted a few times in the document but there is no mention of Citizen Science in

the Heliophysics (Space Weather) Research Program Overview. The first step would in implementing change would be formalizing Citizen Science in Space Weather. An example of that would be including Citizen Science in the Heliophysics research program. ROSES is just one example, other Announcements of Opportunities for Space Weather Citizen Science projects need to come to fruition. Especially agencies such as NASA and the NSF who already encourage and support Citizen Science projects in a variety of fields. The purpose of this is to educate and raise awareness to those in the Space Weather field that opportunities for Citizen Science in Space Weather exist. Once scientists at their respective agency are aware of these opportunities, they will be able to develop a proposal for a project they would like to lead.

A.46	Advancing Collaborative Connections for Earth System Science	TBD	TBD
A.47	Citizen Science for Earth Systems Program	Not Solicited This Year	
A.48	Advanced Information Systems Technology	Not Solicited This Year	
A.49	**Instrument Incubator Program**	**05/31/2019**	**07/12/2019**
A.50	Advanced Component Technology	Not Solicited This Year	
A.51	In-space Validation of Earth Science Technologies	Not Solicited This Year	
A.52	Sustainable Land Imaging - Technology	Not Solicited This Year	
A.53	**Utilization of L- and S- Band Synthetic Aperture Radar Imagery over North America – Joint NASA and ISRO Airborne Campaign**	**05/20/2019 (mandatory)**	**06/19/2019**
A.54	**Decadal Survey Incubation Study Teams: Planetary Boundary Layer and Surface Topography and Vegetation**	**06/17/2019**	**08/01/2019**
B.1	Heliophysics Research Program Overview	N/A	N/A
B.2	Heliophysics Supporting Research	08/06/2019 (Step-1)	09/17/2019 (Step-2)
B.3	**Heliophysics Theory, Modeling, and Simulations**	**10/03/2019 (Step-1)**	**12/03/2019 (Step-2)**
B.4	Heliophysics Guest Investigators Open	05/15/2019 (Step-1)	07/17/2019 (Step-2)
B.5	GOLD-ICON Guest Investigators	Not Solicited This Year	
B.6	Living With a Star Science	TBD	TBD
B.7	**Space Weather Science Applications Operations 2 Research**	**12/16/2019 (Step-1)**	**02/13/2020 (Step-2)**
B.8	Heliophysics Technology and Instrument Development for Science	N/A	08/28/2019
B.9	**Heliophysics Flight Opportunities for Research and Technology**	N/A	08/28/2019
B.10	Living With a Star Strategic Capabilities	TBD	TBD
B.11	Heliophysics Data Environment Emphasis	04/18/2019 (Step-1)	06/20/2019 (Step-2)
B.12	Heliophysics U.S. Participating Investigator	TBD	TBD
B.13	**Outer Heliosphere Guest Investigators**	**10/17/2019 (Step-1)**	**12/03/2019 (Step-2)**

Table 2. ROSES 2019 Solicited Research Programs (Credit: NASA).

The Procedures

Once Citizen Science has become formalized in Space Weather, developing procedures and requirements for the projects will be crucial. The NASA Science Mission Directorate (SMD) recently released a new Policy inviting scientists to utilize citizen science in their research, known as SMD Policy Document SPD-33.[104] This document provides great examples of how a Citizen Science project should be evaluated. The most important element of the proposal will be the scientific merit. Projects could look to solve questions about our Sun, Heliosphere, Magnetosphere, Ionosphere, etc. Another important step in evaluating a project proposal will be looking at the principle investigator and the team he or she has built around them. According to SPD-33, team members should have expertise in fostering broad participation, communication and dissemination of project results. A good example would be an open dialogue of the science team providing the participants with feedback and vice versa. As always, a budget for the project will need to be set and this money should already be in place as per the Memorandum suggested in the prior chapter. It advises agencies to allocate money within their budget for Citizen Science, which many agencies already do. Then the principle investigator and their team would be responsible for budgeting the resources needed to accomplish the projects objective. A simple example would be the cost of an app that the project may need designed for their participants.

Modern society is very much a technology dependent world and smartphone ownership continues to grow rapidly. SPD-33 encourages "utilization of existing platforms and/or existing enthusiast communities to maximize collective impact." This is an opportunity for social media and smartphones to thrive. Future Space Weather Citizen Science projects need to heavily

[104] Science Mission Directorate Policy. SMD Policy Document SPD-33. (2019).

consider utilizing social media platforms such as Twitter where there is already a large Space Weather community. The Aurorasaurus project has already demonstrated how valuable Twitter and other crowdsourced data can be to a Citizen Science project. This ties into the "utilization of existing enthusiast communities," that is stated in SPD-33. Future projects, depending on their goal, could easily collaborate with Aurorasaurus and the HamSCI effort who have dedicated participants that love Space Weather. The opportunity for growth and having a starting foundation of participants is already there. Another useful element mentioned in SPD-33 involves beta testing of the Citizen Science project. This will allow the project team to get feedback from volunteers about the data collection process, see how useful their training was to the participants, examine the quality of the data and receive participant feedback for the overall experience. Citizen Science has proven how valuable of a field it is in many ways and that is why when a project concludes, participants should be guided and retained into other projects in the field. It should be a goal of projects that once their projects completes, they offer other opportunities to their participants. The Citizen Scientists should also be made aware of the concluding results of the project and how their data contributed to the bigger picture, as well as being recognized for their efforts. One of the most important aspects of any successful Citizen Science projects is having a data management plan. That will be one of the most evaluated aspects of a project proposal and was even mentioned in the previous chapter's draft of a Space Weather Citizen Science Memorandum. ROSES would really benefit from utilizing the sections in SPD-33, specifically the evaluation and procedure sections, in their Heliophysics research programs when attempting to include Citizen Science.

Success Metrics

A huge component of any Citizen Science project is being able to gage how successful it has been. Therefore there needs to be success metrics for future Space Weather Citizen Science projects. SPD-33 again provides useful information that can be used as a framework of success metrics for future projects. Revisiting the project's scientific objective is essential and progress towards that objective needs to be evident. A few example questions used to measure success would include: has the project helped improve any models; how has the data been useful; what scientific discoveries made were made, if any? Citizen Science projects are not just about the science but about the participants and their experience too. Another success metric would be evaluating how the project impacted the participants. SPD-33 highlights great examples of this by stating each Citizen Science project should include a "positive, meaningful participant experience such as:

1. Project websites inform users about hypotheses to be tested and questions to be answered.
2. Project websites show good design, as evidenced through User Interface/User Experience usability assessments.
3. Transparency about the use of data created by citizen scientists, intended scientific outcomes and progress.
4. Evidence of two-way communication and feedback."

These are very important elements and standards that all future Space Weather Citizen Science projects should be held to.

A major asset of Citizen Science is the ability for all people of all ages to participate and get some hands-on STEM learning. That is why Space Weather Citizen Science projects must be

able to analyze their projects demographics. Each project will be of different nature but they should attempt to be as inclusive as possible. Broad participation is what makes Citizen Science projects so unique. Another area that projects need to be evaluated on is their ability to promote other Citizen Science projects. A big responsibility in Citizen Science is inspiring the next generation of scientists. Space Weather Citizen Science projects should include links to other opportunities on their website. Many projects can benefit from each other's user platform and therefor cross promoting other projects should be essential. When the science team of individual projects publish any papers related to the project or the data collected, they must acknowledge the contributions made by the citizen scientists and even list them as co-authors if their work warrants that. No individual or team should reap the benefits of work contributed by many Citizen Scientists. With these success metrics in place, agencies will have a process in place to evaluate future Space Weather Citizen Science projects on a year by year basis. This also allows a unique field such as Space Weather to assess these success metrics and how well they apply to their projects.

Chapter VI

BROADER IMPACTS

This chapter will cover ongoing efforts that will help implement or support the use of Citizen Science in Space Weather Policy. This ongoing effort of a Space Weather Certification that will be offered at Millersville University will support the case for Citizen Science in Space Weather. This certification recognizes the importance of communicating space weather phenomena, impacts and engaging the public. A better-educated public, would likely be more enthused to contribute to future Space Weather Citizen Science projects.

A Space Weather Certification

While terrestrial weather and space weather may appear very different, they both cause a wide variety of issues that can affect our daily lives. Common knowledge about space weather seems to start and end with the aurora. And while the aurora is a beautiful Space Weather phenomenon, that is a problem, especially as our reliance on technology continues to advance. Broadcast meteorologists are on the forefront of engaging and educating the public on weather and any possible impacts different weather events may cause. In the early 2000s, the American Meteorological Society (AMS) started integrating the discipline of space weather into the organization. Then in 2008, the AMS Council released its first Policy statement on space weather recognizing the importance of space weather.[105] This Policy statement mentioned how "Universities should broaden their meteorology curricula to include space weather and its effects." Now while some Universities took the initiative and started undergraduate minors

[105] AMS. "Space Weather – A Policy Statement of the American Meteorological Society." (2008).

related to or involving space weather, many Universities still doo not have space weather included in their required curricula. Therefore, meteorologists and broadcast meteorologists in particular, are not properly equipped with the education or training to adequately communicate space weather events or impacts to the public.

In Mid-2016 the AMS council approved an ad-hoc Committee on Space Weather. The goal was to investigate the AMS's role in the space weather arena and determine if there was need for action. Ultimately, the committee had to make a recommendation to the AMS council whether or not they should pursue the possibility of creating a space weather certification through the AMS. To properly determine the correct path, the space weather committee divided into two subcommittees: education and customers. The education subcommittee was responsible for investigating what space weather training exists and whether or not it is applicable to practitioners or students in meteorology. The customer subcommittee was responsible for determining who might be interested in earning a space weather certification. The AMS currently offers a Certified Consulting Meteorologist (CCM) and a Certified Broadcast Meteorologist (CBM) certification. CCMs are "considered experts in the application of weather information to a host of practical challenges ranging from specialized forecasts to engineering design support and expert testimony on weather-related court cases."[106] The CBM program was "established to raise the professional standard in broadcast meteorology and encourage a broader range of scientific understanding, especially with respect to environmental issues."[107] The committee then determined if a CCM-like or CBM-like space weather certification was needed. Based on

[106] AMS. CCM Program. https://www.ametsoc.org/ams/index.cfm/education-careers/ams-professional-certification-programs/certified-consulting-meteorologist-program-ccm/
[107] AMS. CBM Program. https://www.ametsoc.org/index.cfm/ams/education-careers/ams-professional-certification-programs/certified-broadcast-meteorologist-program-cbm/

anecdotal evidence and the training material that existed in the space weather field, it was determined that a CBM-like certification was the best route to pursue.

While the committee remains in the works to create a CBM-like space weather certification through the AMS, Millersville University who happens to be on the leading front of connecting meteorology and space weather at the undergraduate level, have created their own program. This current effort is being led by Dr. Richard Clark, chair of the Earth Science department at Millersville University, Dr. Tamitha Skov, Space Weather Scientist at the Aerospace Corporation and Michael Cook, Space Weather Forecaster for Apogee Engineering. This certification will be an online five course program offered by the Millersville University Earth Sciences Department beginning in the Fall 19' semester. It will begin to bridge the gap between space weather and meteorology as well as serve as an innovative way to successfully engage and inform the public of space weather forecasts and impacts. As terrestrial meteorology was in the 1960s, space weather finds itself in a similar state. Forecast data exists, but it is mostly geared towards specialized audiences, with very little avenue for dissemination to the public. It's a critical time. New modes of communicating space weather to a very eager public are becoming available. Some of these critical paths may be through broadcast and social media, and having actionable forecasts immediately accessible to the public could make all the difference. Again, this goal falls in line with current Space Weather Policy. It harps on how important it is to have actionable products for not only the public but end users of space weather. This is the paradigm shift that the space weather community must strive for—that space weather is real, relevant, and knowable.

Let's examine the five courses; what they are, the goal and how this certification could apply to Space Weather Policy and Citizen Science.

1. **Natural Hazards (3 credits):** This course would be an examination of natural environmental hazards and their associated risks. It would serve as a primer course and is already offered in the Master of Science in Emergency management Program at Millersville University. The objective for this course is to introduce hazards such as hurricanes, earthquakes, tSunamis and space weather. Space weather events are recognized as naturally occurring phenomena as per the National Space Weather Strategy.[10] Like other natural hazards, space weather is a threat to national security and economic vitality. Therefore it is critical to have the ability to protect, mitigate, respond to and recover from severe space weather events.
2. **Space Weather Phenomena (3 credits):** The phenomenology of space weather and climatology course would focus on the phenomena that have societal impacts. It would demonstrate why space weather is important and highlight existing fields and emerging fields. Linkages between space weather and meteorology exist, this course will help show that. The first two parts of the class will describe the "quiet Sun" and the "active Sun", each have their own unique phenomena that comes into focus. Once that is accomplished, the class will finish with how these different events travel through interplanetary space, their arrival time to Earth and the current state of space weather forecasting. Throughout multiple Space Weather Policy documents[7,10,11] a consistent theme has been to better understand space weather phenomenology and how they impact operations, the public and

our national security. This course will properly equip those with the knowledge and understanding of what phenomena have societal impacts.

3. **Space Weather Effects on the Modern World (3 credits):** This is another crucial topic that is repeatedly discussed throughout Space Weather Policy, understanding potential space weather impacts. Space weather is garnering more attention as the entire world becomes so reliant on technology. The effects of space weather go beyond the common knowledge of the aurora that transform our skies to less well known things like radio communications disruptions and the heightened radiation dose airline passengers receive during space weather events. Even some of the ubiquitous GPS errors on today's smart phones can be attributed to space weather. Being able to understand how space weather phenomena impact the modern world and who is impacted, will be the main focus in this course. Space weather effects can be very localized and that will be another important aspect of the course.
4. **Space Weather Decision Making (3 credits):** A "Weather Ready Nation" is a common phrase in the terrestrial weather community. This requires Federal agencies and the public, to understand how to prepare for, respond to and recover from severe weather events or natural disasters. While severe space weather events do not occur as often as terrestrial weather, their impacts can be far greater. It is important for those in the space weather field to understand the proper way to mitigate space weather impacts and how to properly communicate those impacts to the public, decision makers and space weather customers. This course will examine existing documents such as the National Space Weather Action Plan and

the National Space Weather Strategy. In return, this will improve a space weather forecast by understanding the decision maker's perspective and the importance of communicating the impacts. Building a "Space-Weather-Ready Nation" is vital to ensuring a "Weather Ready Nation." The National Space Weather Action Plan states it will require the action of a nationwide network of Governments, agencies, emergency managers, academia, the media, the insurance industry, nonprofit organizations, and the private sector to form the backbone of a space-weather-ready Nation.[11]

5. **Space Weather Broadcast and Communications (3 credits):** A first of its kind, this course will consist of video projects that will demonstrate what the ideal space weather broadcast would look like. The overall theme of this course is to provide effective and informative space weather forecasts. The field currently lacks space weather broadcasts that communicate the potential for space weather events and their impacts to space weather customers and the public. This course provides the knowledge of where to look for publicly available space weather data, products and images to include in an effective broadcast, which products are paired with certain space weather events and impacts, and how to effectively communicate these products to the end users (operations, decision makers and the public).

The certification would supplement current Space Weather Policy and help begin the movement on including Citizen Science in Space Weather Policy. The ultimate goal is to help translate the complex space weather phenomena and jargon, to the public, end users and decision makers. Currently, specialized education and training to communicate space weather phenomena and their impacts to our modern world, do not exist. A wide range of professionals would benefit from this certification. Below is an in-depth look at a few of those professionals:

- **Broadcast Meteorologists**: Meteorologists have an extremely crucial job that goes far beyond making their forecast. That forecast is useless if it cannot be properly communicated to the public and decision makers. The space weather community continues to make strides in their forecasting ability but there remains a gap when it comes to translating or communicating these forecasts. Equipping broadcast meteorologists with the proper training would then allow them to be able to speak on the day to day impacts of space weather, localized space weather effects and even provide insight on any severe events. This also creates a lot of opportunity in terms of Citizen Science. Engaging and educating the public on space weather will help public participation in space weather Citizen Science projects and should also improve the quality of data produced by individuals.
- **Emergency Responders**: The space weather field no longer needs to wait for the "Carrington-like" events to happen in order to be relevant. In September 2017, during the declining phase of Solar Cycle 24, some of the strongest solar flares of the cycle occurred. The morning of September 6th, two X-class solar flares erupted and washed out HF emergency communications for up to eight hours that day. As these solar flares were occurring millions of miles away on the Sun,

Hurricane Irma crossed the Caribbean at Category 5 strength. This caused headaches for emergency responders that were conducting hurricane relief efforts as they rely on HF radio communications. The curriculum for the certification would enable emergency responders to have the knowledge to educate their co-workers and customers about the potential impacts from Space Weather. It will also give them the ability to have situational awareness of the space environment and any potential Space Weather impacts.

- **Other Professionals**: This certification would also be beneficial to operational forecasters, amateur radio operators, earth and space science students, academics, military personnel, business and industry management, and many others. The customer base of Space Weather continues to grow as the impacts are better understood and the modern worlds reliance on technology continues to grow.

Millersville University and their effort in creating this certification will help complement current Space Weather Policy and support the utilization of Citizen Science in Space Weather. It does that by educating space weather stakeholders, customers and the public on Space Weather phenomena and their impacts to our society. This program will be very beneficial to the Space Weather Citizen Science field. That will be accomplished by training the trainers, the professionals who engage and educate the public on a daily basis will be getting trained and educated about Space Weather. In return they will be properly trained and equipped with the ability of inspiring the next generation of Space Weather Citizen Scientists.

Chapter VII

CONCLUSION

Space Weather Policy and Citizen Science are two fields that continue to evolve. Living in such a technology dependent world has really helped raise awareness about Space Weather, especially in the Policy realm. As the realization of Space Weather impacts continues to grow, so has the Policy surrounding the Space Weather community. Each administration has issued their own Space Weather related Executive Order amongst other Space Weather Policy. And as the Policy has continued to evolve, there has remained a few common themes and goals within these documents. They are:

1. Research.
2. Public engagement, education and communication.
3. International Cooperation.

These same themes and goals are exactly what make Citizen Science projects so unique and successful. Citizen Science projects and efforts have continued to grow, especially as the abilities of our smart phones evolve. Projects range from cloud observations, precipitation measurements, helping with cancer research and even classifying galaxies. In the field of Space Weather, Citizen Science projects exist but the true potential has yet to been tapped. Projects like Aurorasaurus and the HamSCI effort have demonstrated how successful these efforts can be. They have helped improve models, provided observational data, engaged and educated the public and utilized international partners and participants. What they are able to accomplish is right on par with what Space Weather Policy is looking for.

The biggest takeaway from the Space Weather Policy review was the absence of Citizen Science in policy. Many Federal Agencies such as NASA and the NSF already fund and utilize Citizen Science projects. There needs to be a concerted effort to have these agencies recognize that Citizen Science is applicable to Space Weather and is being underutilized. Which is why a proposed Memorandum to the head of executive departments and agencies on addressing Space Weather communication and research challenges with Citizen Science, is the perfect way to motivate that effort. The proposed Memorandum laid out principles for effective use of Citizen Science in Space Weather. It then identified responsibilities for the agency coordinator of Citizen Science and what role they will play in helping maximize the potential use of Citizen Science for their agency. Identifying areas within Space Weather that could benefit from Citizen Science was the next topic talked about. It included important steps like utilizing the Solar and Space Physics Decal survey as well as putting out Request for Information surveys to the Space Weather Community to help identify where Citizen Science could contribute to Space Weather. Lastly, this memorandum highlighted some challenges of Citizen Science that future projects could encounter in the Space Weather field. There are not many Citizen Science projects in the Space Weather field but it still touched on some general issues that projects could experience.

With the proposal of what a future Space Weather Citizen Science Memorandum could look like, the next step would be to implement the change. Citizen Science needs to be formalized in the Space Weather community. Orchestrating a concerted effort by federal agencies is the first step and is a must. A great opportunity arose when NASA recently released their annual solicitation for research known as ROSES. While Citizen Science is highlighted a few times throughout the entire document, there is no mention of it in the Space Weather section. This highlights an opportunity moving forward where Citizen Science in Space Weather could

be a solicited topic of research within ROSES. Agencies such as NASA and the NSF already fund Citizen Science projects, the next step would be Announcements of Opportunities for Space Weather Citizen Science projects. Once scientists are made aware of these opportunities, they will be able to write proposals to receive funding and lead their own team or project. NASA recently released SMD Policy Document SPD-33 which does a great job highlighting how current and future Citizen Science projects will be evaluated. This document states that each science Division will invest in Citizen Science as well as report on their annual progress within the field. Most importantly, it documents important elements that all Citizen Science projects should include. Which provides a perfect model for future Space Weather Citizen Science projects, they will not have to reinvent the wheel or start from nothing, the foundation for project planning already exists. Then SPD-33 provides success metrics for how projects should be evaluated on a yearly basis. Again providing guidance for future Space Weather Citizen Science projects as well as an opportunity for these future projects to evaluate the success metrics themselves.

Throughout Space Weather Policy it is repeatedly stated how important it is to understand, forecast and detect Space Weather events and impacts to our modern world. The United States must be able to respond to, mitigate and recover from severe Space Weather events. This is a complex process that involves scientists, forecasters, Policy makers, decision makers and more. The Space Weather Certification that Millersville University will offer provides the proper training to all the professionals just mentioned. A first-of-its-kind certification will provide participants with the expertise to understand and communicate Space Weather phenomena and impacts to a wide variety of stakeholders. But most importantly, this certification will be “training the trainers.” Meaning that all the professionals who obtain this

certification, will be able to train the public and Space Weather customers on this subject matter. They have the ability to inspire the next generation of Space Weather Citizen Scientists. Looking ahead, the field of Space Weather through the media's eye is just scratching the surface. NASA has turned their focus back to human space exploration and has even announced allowing private astronauts to extended stays on the International Space Station beginning in 2021.[108] As the commercial space industry also ramps up along with space tourism, Space Weather will undoubtedly be a center of attention. Formalizing Citizen Science in Space Weather Policy is just the start.

[108] Meghan Bartels. "Private Astronauts Could Spend a Month in Space Under New NASA Plan" last modified June 7, 2019. https://www.space.com/private-astronauts-nasa-commercial-space-station.html

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